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ENERGY CONSERVATION THROUGH IMPROVED WATER TREATMENT

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ENERGY CONSERVATION THROUGH IMPROVED WATER TREATMENT

EXECUTIVE SUMMARY

Water is commonly used to transfer heat within hospital heating, ventilating and air conditioning (HVAC) systems. While water may have excellent heat-transfer properties, all natural waters contain dissolved minerals including the nutrients necessary to sustain microbiological life. Under normal operating conditions, this can lead to the growth of deposits that reduce heat transfer resulting in increased operating and maintenance costs.

Efficient heat transfer requires that heat-exchange surfaces are kept clean. Fouled or scaled surfaces impose an insulating barrier that wastes energy. There are a number of improvements to the water treatment programs and equipment now in place that can lead to conservation of much of this energy and at the same time reduce maintenance and chemical product consumption.

Traditional chemical treatment programs are based upon reducing fouling, scaling and corrosion through the application of proprietary formulated products. These products have generally been developed to maintain a reasonable level of system cleanliness with a minimal level of pretreatment to the water itself. Frequently, users of these materials put more faith in the products than in their own ability. It is the goal, here, to show that cost effective improvements can be made by upgrading both the quality of the water and the measurements taken.

Improved Water Quality

Most hospital cooling tower systems are supplied by raw domestic water supplies with little or no additional treatment. Hospital boilers are relatively low pressure and the water going to them receives little additional treatment other than softening. These waters are not pure; they contain impurities. Material that

enters an HVAC system has a high likelihood of staying and forming deposits. The likelihood of deposits can be reduced if this material is either kept out or removed quickly.

1. A cooling tower, in its normal operation, scrubs impurities from the air. It provides a mechanism for concentrating the level of both dissolved and suspended solids through evaporation. It also provides a breeding ground for microbiological activity. Some form of chemical-treatment program will always be necessary, but even with the best of programs, control can be lost and heat transfer quickly reduced. The tendency for condenser scaling can be reduced through the use of softened water as makeup to the tower or perhaps by utilizing a heat exchanger to isolate the tower system from the condenser. The buildup of suspended solids can be minimized through the use of continuous filtration. With the fouling and scaling tendencies reduced, the tower can be allowed to operate at much higher cycles of concentration thereby reducing the consumption of both water and chemical-treatment products. The higher level of cleanliness attained minimizes fouling of the condenser surfaces which are the most critical component in the system.

2. A boiler produces pure steam for heating purposes and leaves the dissolved solids behind to concentrate in the boiler. To prevent overconcentration, the continuous removal of a small portion of the concentrated water (blowdown) is required to balance the fresh supply of solids being brought in with the makeup. No matter how good the treatment program is, some of the solids will bake on to the hottest surfaces and reduce the heat-transfer efficiency. The blowdown water is **hot** and, unless an effective recovery system is installed, will carry with it a small, but significant fraction of the boiler's energy. By upgrading the water-treatment equipment and recovering a greater percentage of the condensate, the total level of solids entering the boiler can be kept low which means less deposition on the heat-transfer surfaces and less need for blowdown with its energy penalty.

Improved Control

Perhaps the single most cost-effective conservation measure is control. Most analysis programs are geared to product dosage control rather than plant operation.

1. It is biofouling that generally leads to deposits in HVAC condenser systems. All the necessities for microbiological growth are present, yet rarely is monitoring done to measure the biological activity and to control the addition of the necessary biocides. Simple test kits are available to measure bacterial colonies and ensure that biocide addition can be matched to provide the required control.

2. Some of the same analyses routinely performed in most boiler plants can produce the data needed to perform a mass balance throughout the system. This balance then provides the necessary diagnostic tool to measure the magnitude of system losses and enable corrective actions to be taken. Quantifiable objectives can be set with respect to improvements, *eg.* if the boiler operates today with 4 percent blowdown and 17 percent losses, next year's target could be set to reduce these to below 1 and 12 percent respectively.

3. Most water-treatment data tends to be lost in tables and forgotten. With proper data management, it is possible to find the variations and trends that signal possible problems and take corrective action early before significant deposition occurs.

Integration with Other Hospital Needs

A significant capital cost savings is achievable by integrating boiler plant needs with those of other users within a hospital. There are many needs for high quality water within a hospital. Modern systems now installed tend to use double pass reverse osmosis to achieve this requirement. In a typical hospital, the quantity of water needed by the other applications may exceed that needed by the boiler. The same plant can supply both at little additional cost and by integrating both needs only one treatment facility is required.

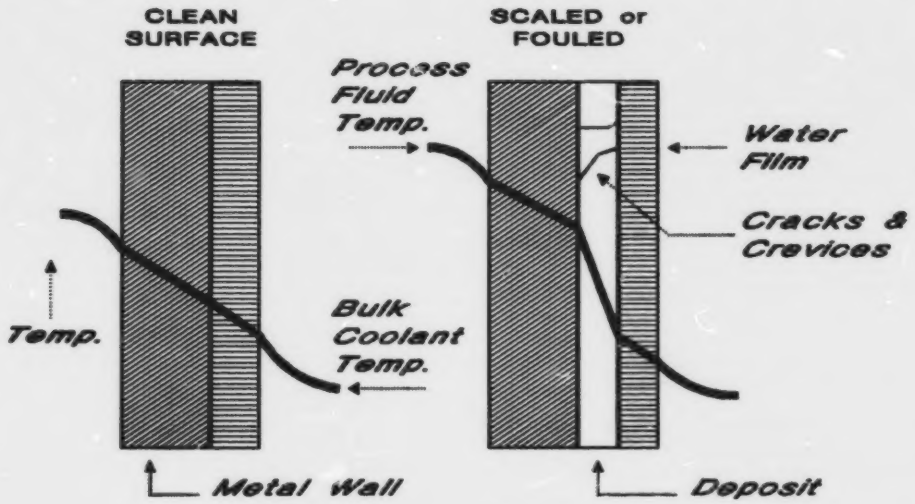
1
WATER AND ITS PREPARATION FOR USE

Water is an excellent heat transfer fluid. It has all the necessary properties needed to transfer heat in the equipment that heats and cools our buildings and industries, but water transfers more than heat. As it flows, it dissolves minerals from the surfaces over which it passes. At the same time, it dissolves carbon dioxide and other gases from the air above it. "Natural" waters are not pure, but contain as major constituents calcium and magnesium and the various carbonate species along with chlorides and sulfates as anions. In addition, the entire periodic table can be present as minor constituents.

Water transports these species as well as the various fragments cleansed from the air or eroded from the shore ... and the various pieces of pipework. These in turn provide all the necessary nutrients to support life: both ours and those of numerous microbiological species - some friendly, others not so friendly. This section looks at the properties that the materials within the water impart to the water and its usage as a heat transfer medium. It also looks at methods to prepare water to the quality needed for the application.

1.1 SCALING & DEPOSITION

Many species form very insoluble materials that precipitate and result in heat transfer loss in a cooling or boiler water system. The term scaling is usually meant to describe the formation of a hard scale at a surface where heat transfer occurs and reduced solubility results due to the higher temperature. Other forms of deposition can occur in the bulk fluid and end up forming a hard deposit after migrating to hot surfaces. The distinction is hard to assess in a given system as the same material can end up as a "scale" by several mechanisms. As the deposit builds up it will result in a loss of heat transfer as depicted in the figure shown on page 2.



TEMPERATURE PROFILE ACROSS HEAT-EXCHANGER TUBING

a. In a **cooling system**, the cooling water flow may no longer provide adequate heat removal. Ever increasing flows will be required until limited by pumping capacity and heat removal becomes "cooling water limited". Increased scale formation will show as increasing component or process temperatures. Depending upon the nature of the process, a maintenance outage (planned or forced) may be required for cleaning.

b. In a **boiler system**, less steam or hot water will be generated from the same quantity of fuel. Increased fuel consumption will be required to meet the specified load. At the same time, the "fireside" will run at an increased temperature which can, as the scale thickness increases, reach a point where

boiler walls are subjected to stresses sufficiently high to cause immediate and permanent damage.

c. In **both cases**, imperfections in the deposit allow for both trapping and concentrating impurities within the surface. While chemical conditions may be reasonable within the bulk fluid, active corrosion may be occurring under the protective cover of the deposit.

Hardness

Hardness results from the precipitation of calcium and magnesium salts as hard scales on heat-transfer surfaces. The major scale producing species are calcium as the carbonate, $CaCO_3$, and magnesium as the hydroxide, $Mg(OH)_2$. These are the least soluble of the calcium and magnesium species present. Carbon dioxide gas dissolves in water and depending upon pH and temperature conditions is in equilibrium with bicarbonate, HCO_3^-, and carbonate, $CO_3^=$, ions. In a typical lake water, the dominant species will be the bicarbonate somewhere around 100 mg/kg. Well waters will tend to contain much higher levels. The bicarbonates are relatively soluble, but heating converts the bicarbonate to carbonate which is less soluble resulting in precipitation of the hardness.

Coping with Hardness

Several options are available for coping with hardness in water supplies. These include:

a. Remove the hardness by precipitation in a controlled manner. This can be accomplished by the use of the lime-soda softener or clarifier (several other terms used to specify clarifiers, including pulsator, refer to specific designs) where increasing the pH and adding carbonate precipitates the calcium and carbonate as calcium carbonate. Well run, this can bring the calcium and alkalinity down to the 50 mg/kg range. This process usually requires a high capital investment and large commitment for space.

b. Remove hardness by exchange of ions such as calcium and magnesium with sodium using ion-exchange softeners. These softeners can then be regenerated with brine.

c. Live with the presence of hardness, but alter the conditions under which calcium carbonate crystals form. A small concentration of a polymeric carboxylic acid such as polyacrylic or polymaleic will cause the crystal to grow in a distorted form that can not link individual units together to form a hard scale. These distorted crystals are removable in bleedoff or blowdown as a soft, suspended sludge.

d. Use of one of the non-traditional non-chemical methods based upon electrostatic or magnetic devices may be considered as an option. At the present time, their effectiveness tends to be supported by testimonials rather than sound technical evidence. There is no evidence that these devices do anything. It is possible that once installed, the mistakes that causing scaling problems are eliminated at the same time giving the impression that the device did it.

e. Accept that treatment is impractical and that efficiencies will drop and that periodic cleanings are inevitable. Before accepting this, it is necessary to recognize that acid cleaning can be a very severe treatment that can cause irreparable damage to system materials. Weaknesses in the metal become very apparent and a system, that did not leak, can begin to leak after acid cleaning.

1.2 MICROBIOLOGICAL ASPECTS OF WATER TREATMENT

Natural waters are abundant in the nutrients needed to sustain life. These are the same nutrients needed to keep all microbiological species growing. Various specialized species can be found in HVAC systems including slime forming bacteria, the most prominent of which are *Pseudomona*. They attach to metal surfaces (not equally to all metals, but they have a strong affinity for the common alloys in HVAC systems) and cover themselves with a *glycocalyx,* a layer of polysaccharide material. In this environment, they are "protected" and able to ex-

tract all the nutrients they need from the water. Their protective coating is sticky and attracts particulate material from the water. As more and more particles attach, the bottom layers die and new outer layers grow to replace them. Eventually a thick covering fouls the heat-transfer surface and reduces HVAC efficiency. The rough surface requires increased pumping power. Chemical analyses show that the deposit is often calcium carbonate with lesser amounts of other species.

The structure of the deposit is not perfect. It has pores and cracks in which other species can concentrate in a protected environment. This provides a mechanism for both electrochemical and microbiological corrosion of the metal surface under the deposit.

Cleaning is eventually required and usually involves some type of acid as calcium carbonate readily dissolves in acid. A very small percentage of the deposit remains behind attached to the surface. This includes materials such as fibres and alumino-silicates. This surface is not clean enough and is almost "prepared" for a new layer of biological growth. In a typical plant, it might take ten years to form a deposit thick enough that action must be taken. If that action is acid cleaning, the cleaning may then have to be repeated on an annual basis and can lead to acid-induced equipment failures.

Algae thrive on sunlight. They grow and form dense green-coloured mats that clog piping preventing adequate water flow. While the actions of most bacteria tend to occur inside the pipework, the actions of algae tend to be very visible and give a strong indication that all is not under control.

Fungi attack the wood in the cooling tower and reduce its structural strength. *Basidiomysetes* consume the wood as a nutrient, particularly in the plenum chamber and other non-flooded parts of the tower. In the flooded regions, the filamentous molds rot the surface by consuming cellulose.

Coping with Microbiological Activity

Microbiological activity is alive. Any control mechanism must kill it. There are two general approaches available:

a. **Oxidizing biocides** include chlorine, chlorine dioxide and ozone. They kill by destroying the molecules that make up the various species. They are non specific and will attack all species, but may also attack system components *eg.* ion-exchange resins.

b. **Non-oxidizing biocides** include a number of proprietary products. They kill by upsetting the chain of chemical or biochemical events that allow the species to flourish. Some are useful against one specific species while others will kill a broad spectrum of species.

Algae require light to survive. The simple addition of cover on a cooling tower deck will reduce their access to it and reduce their growth.

1.3 WATER AND CORROSION

Conduction of an electrical current needs charge carriers and a force or potential to drive them. This is normally accomplished by the electrons in metallic wires pushed by the potential of a battery or generator. Conductivity is not restricted to electrons within wires. Conductivity can occur in chemical solutions through another mechanism. Consider the case of water, made conducting with the addition of a little sulfuric acid. If a relatively low (about 2 V) DC source is connected to this, gas will be evolved at each of the two electrodes.

a. At the negative electrode, the volume of gas is twice that at the positive electrode. The gas burns in air and can be identified as hydrogen. The reaction that occurs at this electrode is the gain of electrons by water to give hydrogen gas. Reactions involving a gain of electrons are called **reduction** reactions and the electrode where reduction occurs is called the **cathode**.

b. At the positive electrode, the lower volume gas is identified as oxygen. Water has given up electrons to form oxygen. Reactions involving a loss of electrons are called **oxidation** reactions and the electrode where oxidation occurs is called the **anode**.

Whenever there is a reduction reaction there must be an accompanying oxidation reaction. Often the contraction **redox** reactions is used. To always remember which is which, think of the line **LEO says GER.**

Loss of Electrons = Oxidation

and

Gain of Electrons = Reduction

Conductivity within solutions is the transfer of electrons through a pair of redox reactions at the two electrodes.

Many combinations may undergo a reaction with an applied voltage. Many others may undergo the reaction spontaneously without an applied voltage; they only need a completed current path. Those that require an applied voltage are **electrolytic** reactions and those that occur spontaneously are **galvanic** reactions.

The requirements for a Galvanic cell are:

- a material to be oxidized
- a material to be reduced
- a conducting solution
- a completed current path

They can be met by well engineered cells such as batteries or essentially any water-containing pipework system. Measurements of cell potentials of various materials have been made and assembled into a table of **Standard Oxidation Potentials**. Potentials for all the redox half reactions are measured relative to a standard which is the hydrogen electrode. The material with the highest oxidation potential will be the anode and the one with the lowest (or highest reduction potential) will be the cathode. What does this mean in the real world? In a cooling water system, a **conducting fluid** circulates through pipework containing carbon steel pipes for the main circuit and copper (or copper alloy) heat-exchanger tubes. From the table of Standard Potentials:

Iron (steel) $E_{ox} = +0.44$ V

Copper $E_{ox} = -0.34$ V

The steel, having the higher potential, will be the anode while copper becomes the cathode. The only other requirement is the completed current path which is supplied by the flanges or union joining these two together. All the requirements have been met for a galvanic cell. A potential will be produced between steel and copper and a current will flow. Within the water system, the current is carried by redox reactions and the movement of ions in solution.

a. At the anode, iron will be oxidized.

$$Fe_{metal} \rightarrow Fe^{3+} + 3e^-$$

The iron is going into solution, *ie.* **it is being attacked as a result of this Galvanic action.**

b. At the cathode, the copper, being in the form of the metal, is already in the reduced form. Reduction will more likely be that of the water to produce hydrogen gas. The copper is actually protected by this combination.

In any combination of copper and steel, it is always the steel that will be attacked or corroded. The Galvanic action provides the driving force and oxygen the food to get it into solution. The iron oxides produced will migrate through the system and deposit on heat-transfer surfaces lowering their ability to function.

Metals at the higher end of the table will almost always be anodes and as such their use in many systems is as a protective or **sacrificial** anode. The most common metal is zinc which is plated onto steel to produce galvanized steel or may also be used in the form of replaceable electrodes.

Coping with Corrosion

Corrosion, at least that of a Galvanic origin, can be reduced by either stopping the cell reaction or by altering the cell to make the critical metal into the cathode.

a. Sacrificial electrodes made from materials, such as zinc, will make a carbon steel pipe cathodic and thus protected.

b. Cathodic protection systems apply a DC potential equal to, but reversed to that of the cell made from the system materials. If the voltage is just balanced, no reaction can occur. Control problems may make it easier to apply a slightly higher potential making the carbon steel cathodic.

c. Protective coatings such as paint really do nothing to the electrical balance, but hide the surfaces and thereby protect them by blocking the current path. If damaged, corrosion will occur, but only at exposed surfaces.

   The use of decorative coatings such as tin can protect the surface, but only as long as it is intact. If damaged, the steel will be anodic compared to tin. The tin actually accelerates corrosion once damaged.

d. Insulated couplings can break the main current path to reduce corrosion. If insulating gaskets are used, it's important that the nuts and bolts are also insulating materials.

e. Corrosion inhibitors fit into categories: anodic and cathodic.

   Cathodic inhibitors block the contact between the surface and hydrogen gas reactions. They do this by forming a thin surface barrier. Typical cathodic inhibitors are polyphosphates and phosphonates. If the concentration is low, there will be an increase in general corrosion rates averaged over the entire surface.

Anodic inhibitors protect by deliberately oxidizing the surface in a controlled fashion usually forming one of the more stable oxides such as gamma-iron oxide or magnetite. This is accomplished with products such as chromates, molybdates and nitrites. It is important that sufficient product is present. If the dosage is too low, corrosion tends to concentrate in unprotected regions and form pits.

Formulated products are often based upon blending both types to get a synergism that greatly improves the protection.

f. Oxygen scavengers inhibit corrosion by starving the process of the oxygen needed to get iron into solution. The use of some of these products, *eg.* sulfites, on their own is not adequate as they can not cope with local ingress of air. Some oxygen scavengers also act as reducing agents and modify oxide coatings to more stable forms. These include materials such as hydrazine, which on its own makes an excellent inhibitor by forming a protective magnetite surface.

1.4 COMBINED EFFECTS

Any or all of these processes can occur at the same time. *eg.* sulfate reducing bacteria can attack iron surfaces underneath the fouling brought about by slime formers or scale. Problems are rarely of single origin. Often scaling is diagnosed when the real problem is microbiological fouling. In both cases, chemical analyses would indicate the scale material to be calcium carbonate.

Water systems must be treated and the treatment program must address all three areas: scaling, corrosion and microbiological activities.

1.5 PRETREATMENT OF WATER FOR USAGE

As discussed in the previous section, water contains a number of impurities that limit its use for heating and cooling operation. Having looked at the limitations, we will now look at the steps needed to pretreat the water for usage in various applications.

Suspended Solids

Suspended solids cover the range from floating debris through to the ultra-small particles referred to as colloids. The larger material can clog lines and cause damage to mechanical components such as pump impellers. The smaller particles can end up as deposits farther down the line and reduce efficiency of ion-exchange materials or heat exchangers. The treatment required will be dependent upon the size of the material.

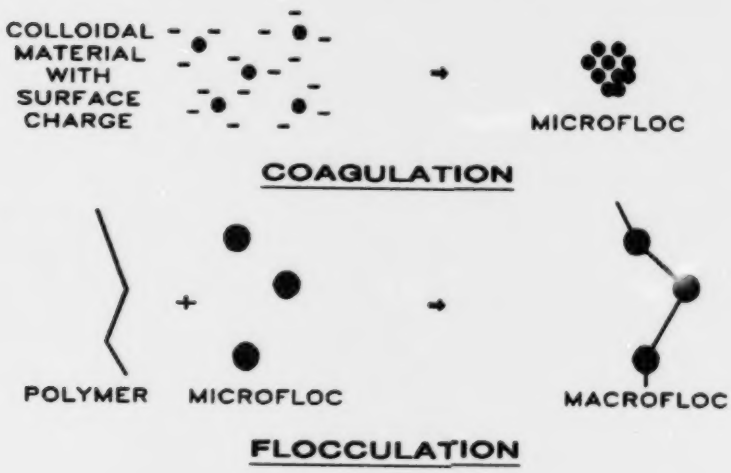
Particle Size	*Filtering Media*
large debris > 1 mm	*bar and wire screens*
<1 mm – 0.1 mm	*sand/anthracite filters* *strainers* *centrifugal filters*
<0.1 mm & colloids	*coagulation/flocculation*

Coagulation/flocculation procedures are required to remove the very fine particles that may be suspended in the water. The main product used for this is alum (aluminium sulfate) with a polyelectrolyte although other variations are common including lime and ferrous sulfate clarifiers and in-line polymer addition to sand filters.

The very small particles tend to remain suspended due to their slow settling rate. To remove them it is essential that they clump together into larger particles that will settle. Most small particles possess a surface charge and, as like charges repel each other, the particles also repel each other. The first stage in the process **coagulation** neutralizes the surface charge allowing the fine particles to join together to form into clumps or **microflocs**.

Microflocs grow slowly. The growth into larger **macroflocs** can be accelerated by **flocculation**, a process where the addition of a polyelectrolyte acts as a bridge to link several macroflocs together. The chemical bonding, between the polymer and the microflocs, is weak and could be disturbed by excessive tur-

bulence. For this reason, coagulation is carried out in a region of flash mixing and the flocculation stage is done in a calm region of the vessel. The clear liquid is then passed through a sand filter to remove any residual floc.



Microbiological Control

The most common biocide is chlorine fed as either gas or liquid. In water there is an equilibrium among three species: chlorine, hypochlorous acid and hypochlorite ion.

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl \quad \text{and} \quad HOCl \rightleftharpoons H^+ + OCl^-$$

The primary action is by hypochlorous acid. It is the dominant species in the pH 6.5-7.5 range. Chlorine is generally added intermittently as a shock treatment. Domestic systems generally leave a residual of about 0.3 mg/kg. Chlorine is losing favour in areas where the water supply is heavily contaminated. Products ranging from chloramines to chloroform can be formed. Chloroform is now considered to

be carcinogenic. Alternative products gaining acceptance include chlorine dioxide and ozone.

Most municipal water supplies provide a water that has been treated to this stage. Additional microbiological control would be required in a cooling tower which is continually picking up matter from the atmosphere. The modern all-organic treatment programs for cooling towers tend to operate at pH ranges of 8.0 and up where there is little HOCl left. There is some controversy as to whether the effectiveness of chlorine is really diminished at these high pH ranges. Chemical equilibria are dynamic processes and may be able to replace the hypochlorous acid as it is used up. If the time scale for HOCl to act is long, it may be effective. If the time is short, the HOCl can not be replaced quickly enough to be effective.

Dissolved Solids

The various ions can be removed by different combinations of ion-exchange or reverse osmosis equipment depending upon the water quality required for the process. For simplicity here, an arbitrary choice of water has been made and a series of tables show the change in effluent quality from the various treatments. All analyses are at the exit of the resin, except the cation which is at the exit of the degasser. All ionic concentrations are reported in mg/kg as $CaCO_3$.

Ion Exchange Resins

These are synthetic polystyrene beads containing acid or base functional groups. In water treatment, they possess the ability to exchange one ionic species for another. Water is passed through a bed containing resin beads and various ions are removed and replaced with others. This process can continue until all the exchange sites on the resin are saturated. The bed can then be regenerated by passing a regenerant solution through the resin to release the exchanged ions, usually to the sewer. Ion-exchange resins fit into two main classes as shown on the next page.

ION-EXCHANGE RESIN CLASSES			
Resin Class	Regenerant	Major Ions Exchanged	
Acid (Cation)	Strong acid	hydrogen for	calcium magnesium sodium iron
	Brine	sodium for	calcium magnesium iron
Base (Anion)	Strong base	hydroxide for	bicarbonate carbonate chloride sulfate
	Brine	chloride for	bicarbonate carbonate sulfate

a. **A strong acid resin operating as a softener:** The softener converts the hardness producing cations into sodium, but has no effect upon the anions. The total dissolved solids and alkalinity remain unchanged. The potential for scale formation is much reduced. This water is generally considered to be suitable for feed to both cooling towers or boilers with a suitable corrosion inhibitor. The resin is regenerated with a brine solution.

SODIUM SOFTENER EFFLUENT QUALITY		
SPECIES concentration as mg/kg of $CaCO_3$	RAW WATER	SODIUM SOFTENER
Sodium	50	550
calcium	300	<2
magnesium	200	<1
hydrogen	nil	nil
total cations	550	550
bicarbonate	400	400
carbon dioxide	nil	nil
chloride	50	50
sulfate	100	100
total anions	550	550
iron	0.6	<0.1
silica	10	10
approximate pH	7	7

b. **A strong acid resin in the hydrogen form:** All of the cations will be converted to hydrogen (except for a small sodium leakage) making the solution acidic, converting the bicarbonate to carbon dioxide gas, which is then removed by a degasser. The regenerant is usually a dilute solution of a strong acid such as sulfuric or hydrochloric.

STRONG CATION EFFLUENT QUALITY

SPECIES concentration as mg/kg of $CaCO_3$	RAW WATER	STRONG ACID CATION
Sodium	50	<5
calcium	300	<1
magnesium	200	<1
hydrogen	nil	145
total cations	550	150
bicarbonate	400	0
carbon dioxide	nil	*
chloride	50	50
sulfate	100	100
total anions	550	150
iron	0.6	<0.1
silica	10	10
approximate pH	7	3

* removed by degasser.

This water will be of low alkalinity and acidic and requires a corrosion inhibitor before it can be used in carbon steel systems. Vessels and pipework will normally be lined with polyethylene, teflon or some other inert material.

c. **Combinations of the above**: By blending a sodium with a hydrogen-form resin in parallel, an intermediate water considered to be suitable for low pressure boiler feed can be produced. It will have reduced alkalinity and essentially none of the scale forming cations. This type of system is referred to as **split stream**. An alternate arrangement can be made by series rather than parallel operation to get more dealkalization. The strong cation resin in the H or acid form resin comes first then the degasser. The acidic effluent will then displace sodium from the softener to raise the pH.

d. **Weak acid resin**: Strong acid resin is expensive to regenerate. By substituting a weak acid resin, the only difference is that the weak acid resin will not remove sodium. Similar series and split-stream arrangements can be made to those shown above.

SPLIT-STREAM EFFLUENT QUALITY+

SPECIES concentration as mg/kg of $CaCO_3$	RAW WATER	WEAK ACID CATION	SODIUM SOFTENER	SPLIT STREAM (50:50)
Sodium	50	50	150	100
calcium	300	<1	<2	<2
magnesium	200	<1	<1	<1
hydrogen	nil	100	nil	50
total cations	550	550	150	350
bicarbonate	400	0	400	<200
carbon dioxide	nil	*	nil	*
chloride	50	50	50	50
sulfate	100	100	100	100
total anions	550	550	150	350
iron	0.6	<0.1	<0.1	<0.1
silica	10	10	10	10
approximate pH	7	4	7	5-6

* removed by degasser, + assuming 50:50 ratio of Na:H

e. **Chloride dealkalization**: Following a sodium softener with an anion in the chloride form converts all of the anions to chloride. In this example, 550 mg/kg as chloride. This combination may remove alkalinity, but it also carries the same high total dissolved solids level into a boiler with the same high or higher blowdown requirements. Regeneration requires an alkaline brine solution containing at least 10 percent of the active material as caustic soda. Regeneration with brine by itself does not produce an effective regeneration.

Other methods for alkalinity reduction can also include the addition of a mineral acid or the use of cold/hot lime softening. The use of a mineral acid merely converts alkalinity to chlorides or sulfates, *ie.* there is no reduction in total dissolved solids. Lime softening reduces the ion exchange load but requires elaborate equipment.

CHLORIDE DEALKALIZER EFFLUENT QUALITY

SPECIES concentration as mg/kg of $CaCO_3$	RAW WATER	SODIUM SOFTENER	CHLORIDE DEALK-ALIZER
Sodium	50	547	547
calcium	300	<2	<2
magnesium	200	<1	<1
hydrogen	nil	nil	nil
total cations	550	550	550
bicarbonate	400	400	<2
carbon dioxide	nil	nil	nil
chloride	50	50	547
sulfate	100	100	<1
total anions	550	550	550
iron	0.6	<0.1	<0.1
silica	10	10	10
approximate pH	7	7	7

f. **Demineralization**: An H-based strong cation resin followed by a degasser and an OH-based anion resin removes essentially all the ionic species and replaces them with hydrogen and hydroxide which recombine to produce water. There is a small leakage of sodium, chloride and silica. Most of this can be removed by adding a mixed-bed unit as a polisher to act on this leakage. The mixed bed must be separated into separate cation and anion resins for regeneration. The cation resin will be regenerated with acid and the anion with caustic soda.

Reverse Osmosis

This relatively new process offers an alternative to ion-exchange demineralization, particularly for lower volume requirements. Purified water is prepared by permeation through a semi-permeable membrane. Rejection can be up to 95-99 percent of the ionic species. Water quality will be almost as good as that through the combination of strong cation/degasser/strong anion. Approximately two thirds of the water will pass through the membrane to produce a high quality **permeate** (product). The remaining one third will be the **reject** and

DEMINERALIZER EFFLUENT QUALITY

SPECIES concentration as mg/kg of $CaCO_3$	RAW WATER	STRONG ACID CATION	STRONG BASE ANION	MIXED BED POLISHER
Sodium	50	<5	<5	<1
calcium	300	<1	<1	<0.1
magnesium	200	<1	<1	<0.1
hydrogen	nil	145	0	0
total cations	550	150	<5	<1
bicarbonate	400	0	0	0
carbon dioxide	nil	*	0	0
chloride	50	50	<5	<1
sulfate	100	100	0.1	0.1
total anions	550	150	<5	<1
iron	0.6	<0.1	<0.1	<0.1
silica	10	10	<1	<0.1
approximate pH	7	3	9	7

* removed by degasser

REVERSE OSMOSIS EFFLUENT QUALITY

SPECIES concentration as mg/kg of $CaCO_3$	RAW WATER	PERMEATE (PRODUCT)	REJECT (WASTE)
Sodium	50	<2	150
calcium	300	<5	900
magnesium	200	<4	600
hydrogen	nil	nil	nil
total cations	550	<11	1650
bicarbonate	400	<15	1200
carbon dioxide	nil	nil	nil
chloride	50	<1	150
sulfate	100	<2	300
total anions	550	<20	1650
iron	0.6	<0.1	<2
silica	10	<1	30
approximate pH	7	6.5	7

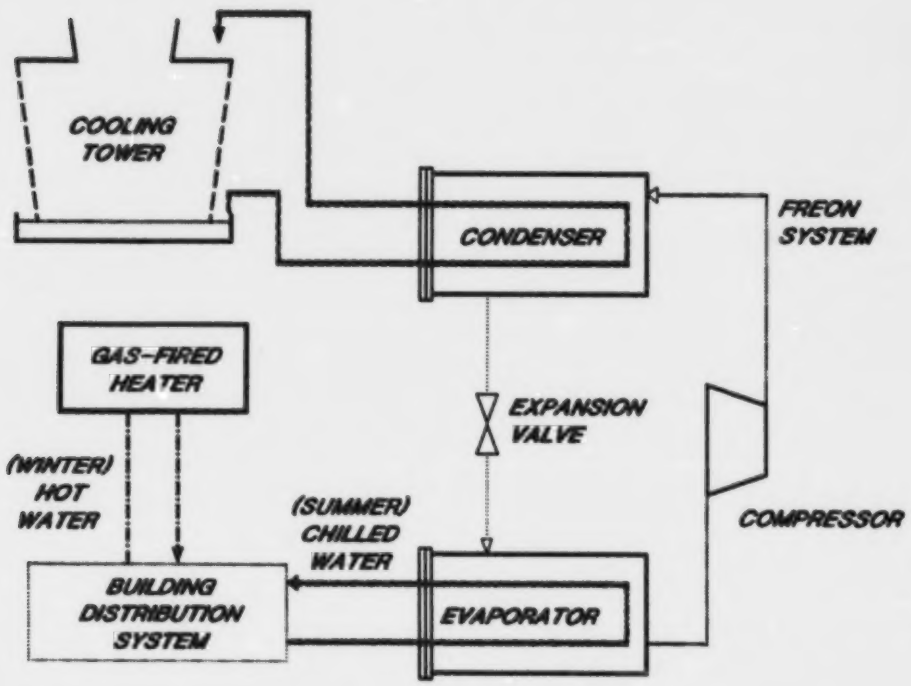
will carry a high solids level to the sewer. To protect the membranes, it is common to have a both a filter and an ion-exchange softener located ahead of it.

Reverse osmosis has the advantage over ion-exchange techniques that it does not require the handling of regenerant solutions. It does, however, have very high water usage with one third as reject. This quantity can be reduced by cascading units. Reverse osmosis has not yet received wide acceptance in Canada. This situation is changing as systems are becoming more cost effective.

2

IMPROVING ENERGY EFFICIENCY IN HVAC SYSTEMS

HVAC systems are based upon compression of freon or absorption by lithium bromide. The figure shows a compression type system where freon moves heat. Freon gas is compressed, and in the process evolves heat. Cooling is required to remove this heat and allow the gas to condense into liquid freon in the condenser. The cooled liquid is now allowed to expand into gaseous freon in the evaporator section. This expansion cools the freon. The cool gas moves on to the compressor. There are two basic water containing circuits:

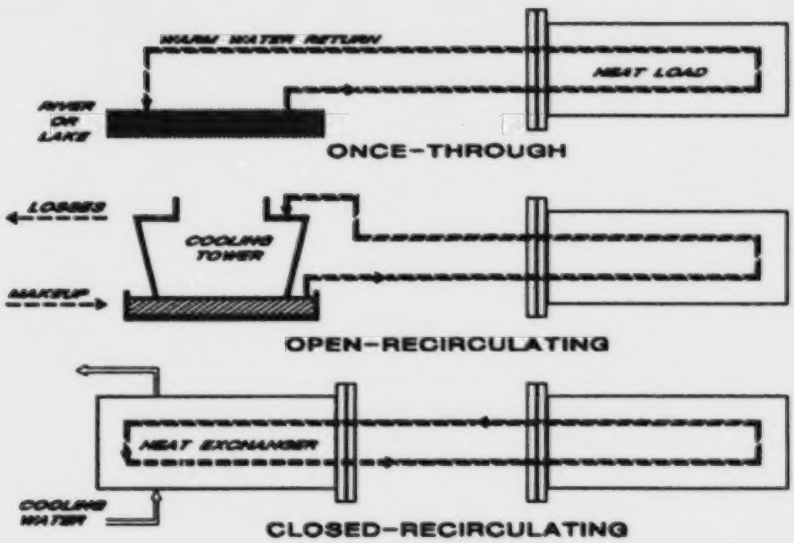


BUILDING HVAC WATER SYSTEMS

a. The **condenser water** system cools the hot compressed freon gas to convert it to liquid.

b. The chiller or evaporator is cooled by the expanding freon to supply the **chilled water** for the building. In winter this same circuit switches to hot water.

Cooling systems can be divided into three categories based on the availability and use of water. Each of the three systems has its own distinct problems that are different from the other two. Two of the systems, once-through and closed-recirculating, are relatively simple to understand. The third, open-recirculating, is more complex and requires the major portion of the following discussion. HVAC systems utilize all three types of systems interconnected. With attempts to conserve water, once-through systems are now becoming rare compared to the other two types.



CLASSES OF COOLING WATER SYSTEMS

For comparison purposes, this section looks at the three types of systems and calculates water and product usage based upon a large plant requiring a total flow of 20,000 usgpm to cool its various heat exchangers. It will be assumed that the temperature rise in the cooling water after leaving the heat exchangers will be 5°C or 9°F and that the plant operates 365 days per year.

2.1 ONCE-THROUGH SYSTEMS

These systems are the simplest to design and the most expensive to treat. Cooling water is pumped directly from the source to the heat exchanger. It picks up heat then passes directly to a drain. The use of once-through systems is usually restricted to either very small systems (eg. a laboratory condenser) or to major industrial plants that pump their own water directly from a lake or river. Once-through systems are far too costly for plants that purchase water. As the water passes through so quickly, treatment programs must be based upon simple inorganic products that are both inexpensive and relatively free of adverse environmental impact.

As a minimum, some form of biological control is needed to suppress biologically induced corrosion and fouling. Chlorine, chlorine dioxide and ozone are the only biocides that can be used. Because of the large flows involved, their use tends to be a shock treatment for a few hours per day. Chlorination is often assisted, in industrial applications, with the addition of a wetting agent.

Corrosion control can be accomplished with one of two products. All others are either two expensive for once through operation or too hazardous for discharge to the environment on a continuous basis.

a. Condensed polyphosphates at threshold levels as low as 1.5- 2.0 mg/kg (as orthophosphate) can be sufficient to build up a surface film containing calcium, polyphosphate and iron. This film can control corrosion to acceptable levels by blocking the cathodic reaction. At these concentrations, the polyphosphate also starts to exhibit a distorting effect upon the formation of calcium carbonate crystals. The distorted crystals do not form as hard a scale as do untreated crystals.

b. Sodium silicate in the 30-50 mg/kg range can also control corrosion within acceptable levels by forming a thin silicate coating on metal surfaces.

Both polyphosphates and silicates find extensive use in municipal domestic water supplies to eliminate "red water" or rust formation in the many kilometres of piping required to deliver water to individual residences and commercial properties.

Many plants try to operate once-through systems without treatment. The pipe walls quickly become heavily tuberculated. This tuberculation covers an attack, probably of both galvanic and biological origin, that leads to wall thinning and eventual failure. The rough surface may require increased pumping power to maintain flows.

WATER AND CHEMICAL REQUIREMENTS: ONCE-THROUGH		
Makeup rate	20,000 usgpm 28.8 million usg/day	
Time for 20,000 usg makeup	1.0 min	
Typical treatment program	daily	annual
polyphosphate @ 10 mg/kg	108 kg	39,600 kg
@ $1.50/kg	$162	$59,400

To operate this plant, almost 30 million usg of water will be required per day. This would be discharged at a temperature 5 Celsius degrees above that of the ambient water. Depending upon the location, there could be charges for the use of the water, its discharge and limitations on the allowed temperature rise over different periods of the year.

2.2 OPEN-RECIRCULATING SYSTEMS

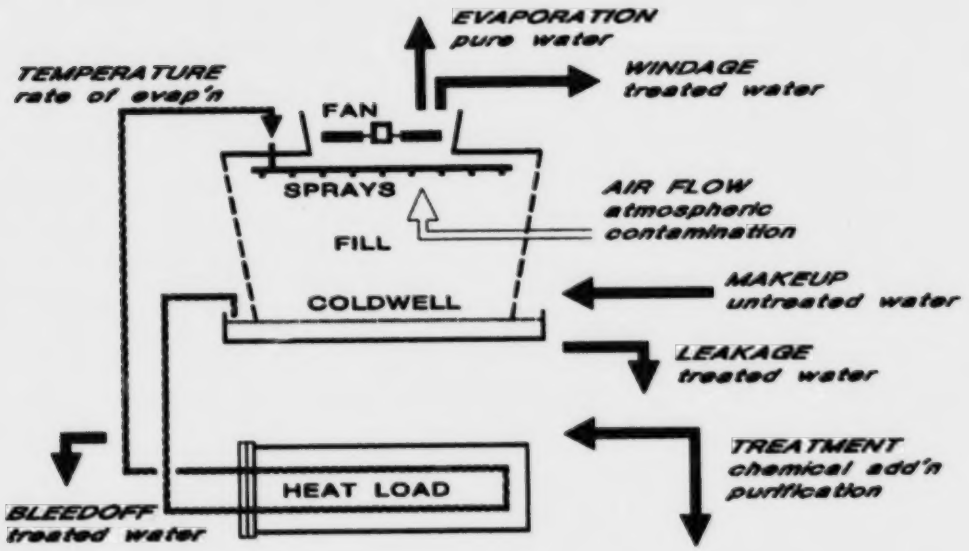
Water usage can be reduced by utilizing evaporative cooling for removal of heat from the water to allow its reuse. The warmed water, returning from the process, is sprayed on to the cooling tower. Evaporation cools the water which then collects in the coldwell or sump ready for recycling. Fresh water is added only to replace evaporation and system losses. Typical makeup requirements are

only 2-3 percent of the flowrate and water will reside in the system from hours to days. The water in the coldwell becomes more and more concentrated as evaporation continues. A controlled **bleedoff** limits the maximum concentration of the various dissolved species especially hardness.

The concentration reached is measured in **cycles of concentration** or **COC** which is a measure of a given species in the concentrated water *vs* the concentration of that species in the makeup. As an example:

$$COC = \frac{[Cl] \text{ in tower}}{[Cl] \text{ in makeup}} = \frac{120 \text{ mg/kg}}{30 \text{ mg/kg}} = 4.0$$

The use of chloride may give misleading results in some geographical areas where chloride can be carried in the atmosphere *eg.* towers located near the sea or operated in the winter near a salted highway. Cooling tower sprays tend to pick up particulate and microbiological material from the atmosphere leading to severe fouling problems.



COOLING TOWER CONTROL DYNAMICS

Treatment of open-recirculating systems tends to be much more complicated than for an open system due to the dynamic nature of the system. Pure water is lost to the atmosphere by evaporation leaving behind a residue. At the same time the scrubbing action of the sprays picks up gases and debris from the atmosphere. Treatment requires establishing control of corrosion, suspended material and microbiological life. The relatively closed operation allows for more expensive formulations. The required chemical dosage is related to the water used within the system. The dynamics are dependent upon losses of treated water as well as losses of untreated water.

a. **Evaporation** removes heat from the water by allowing those molecules with the highest kinetic energy ie. temperature to escape. Water that is lost is pure and carries no treatment as the treatment products stay behind. The loss of water by evaporation, as a percentage of the total, is directly related to the temperature difference across the tower.

$$\%E = \frac{\text{delta-T}}{10} \quad \text{with T measured in Fahrenheit}$$

b. **Drift** or **windage** is water carried as entrained droplets by the wind. This is treated water, ie. system water. The losses are dependent upon the design of the tower, wind conditions at the time and other such factors. As a general rule the following values can be used as a guide:

Class of Cooling Tower	*Percent Windage*
spray ponds	*1.0 – 5.0*
natural draft towers	*0.2 – 1.0*
induced draft towers	*0.02 – 0.3*
forced draft towers	*0.02 – 0.3*

c. **Bleedoff** is water drained from the system to prevent overconcentration or operation at too many COCs. This value may be established to maintain a desired level or it may be an operating characteristic of the system *ie.* **leakage**.

Cycles of concentration are derived from the three:

$$COC = \frac{xE + xW + xB}{xW + xB}$$

where $xB = \frac{\text{delta-T}}{10(COC-1)} - xW$ and $xMU = xE + xW + xB$

A common fallacy in calculating product requirements is that the product consumption is directly related to the makeup added to the system. This is not correct as makeup to replace evaporation losses does not require additional treatment.

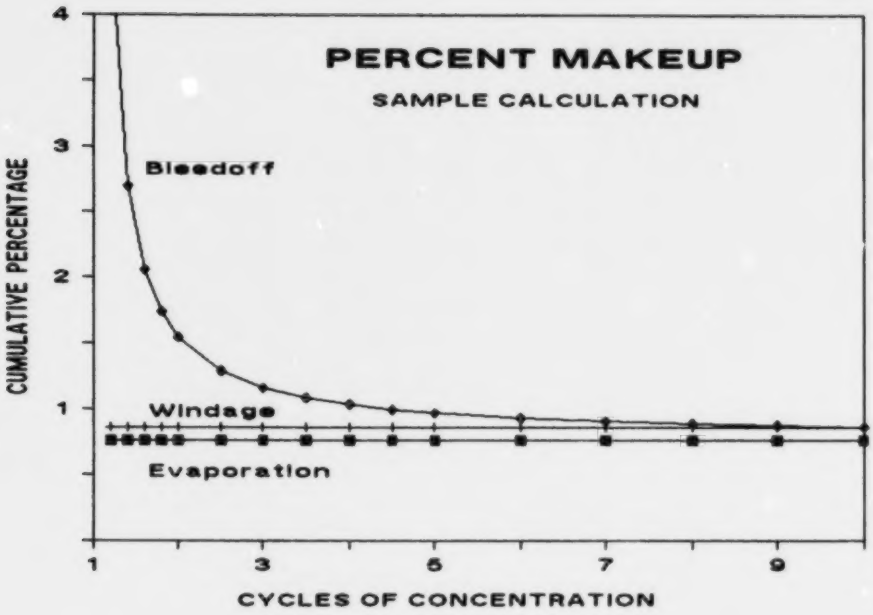
- Evaporation losses are fixed by system design and the delta-T across the system.

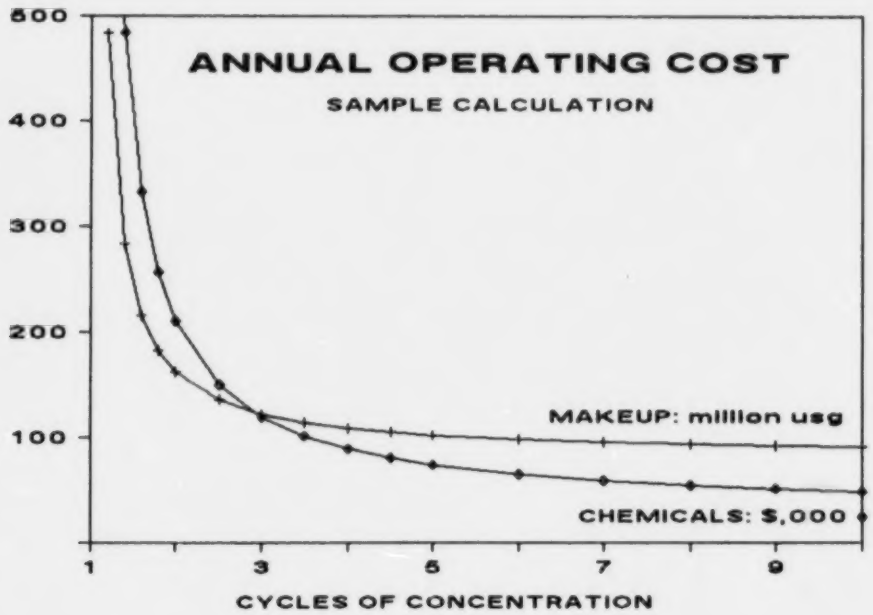
- Windage losses are fixed by system design.

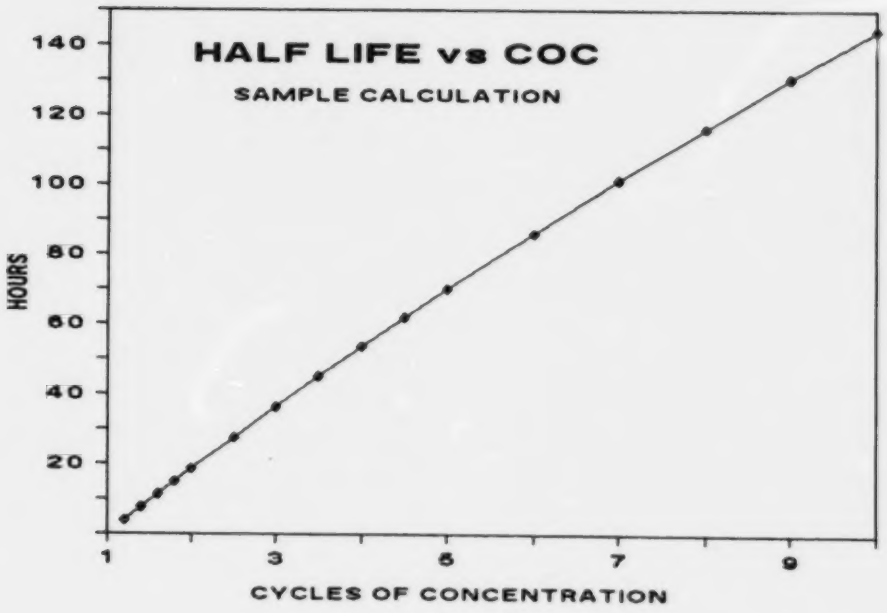
- Bleedoff can be adjusted within a fixed range that is system dependent.

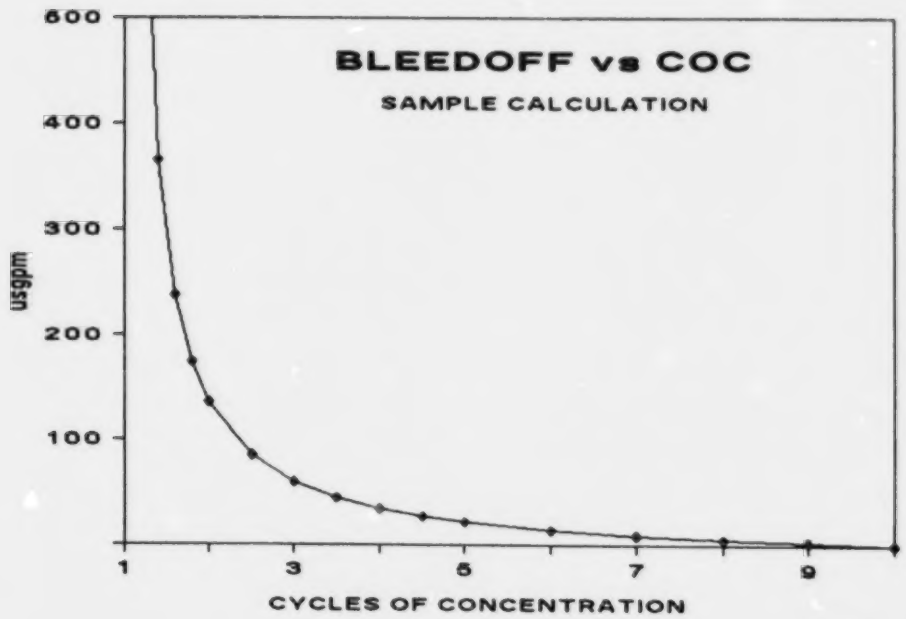
The graphs[1] on the following two pages summarize calculations made on a cooling tower with a cooling water flow of 20,000 usgpm and 9°F delta-T. The calculation has been done for a range of cycles of concentration up to the maximum achievable for the conditions. With high bleedoff, the number of cycles of concentration is low. As the bleedoff is reduced, the number of cycles of concentration continues to increase until bleedoff becomes zero. In a typical HVAC application, where the delta-T is low, the maximum number of cycles attainable may

1 Data calculated by CTOWER-1, a LOTUS 1-2-3™ spreadsheet (C) 1987 by MARVIN SILBERT AND ASSOCIATES


PERCENT MAKEUP
SAMPLE CALCULATION
CUMULATIVE PERCENTAGE
4
3
2
1
Bleedoff
Windage
Evaporation
1
3
5
7
9
CYCLES OF CONCENTRATION


ANNUAL OPERATING COST
SAMPLE CALCULATION
500
400
300
200
100
MAKEUP: million usg
CHEMICALS: $,000
1
3
5
7
9
CYCLES OF CONCENTRATION


HALF LIFE vs COC
SAMPLE CALCULATION
HOURS
140
120
100
80
60
40
20
1
3
5
7
9
CYCLES OF CONCENTRATION


BLEEDOFF vs COC
SAMPLE CALCULATION
usgpm
600
400
300
200
100
1
3
5
7
9
CYCLES OF CONCENTRATION

be 4-8. In an industrial application, where the delta-T is high, it may be possible to attain over 20 cycles. As the number of cycles rises, so also do concentrations of scale forming species and the need for a program to control them.

Makeup water requirements decrease rapidly with the first few cycles of concentration, with almost no change above 5 COC. However, chemical costs continue to drop as the products are concentrated within the system.

The most effective corrosion inhibitor is **chromate** which acts as an anodic inhibitor forming a stable gamma-iron oxide film. With the increasing consciousness of the environment, chromates were first reduced from the 150 mg/kg region to the 30-50 mg/kg region by using synergistic blends with zinc. Newer formulations eliminate chromate and utilize blends of biodegradable organics such as phosphonates and azoles.

Scaling tendencies can be reduced through the use of pretreatment of the water through techniques such as softening or reverse osmosis, but the cost for their application is high and as yet not widely utilized. On the other hand, the nature of the scale can be changed through the use of scale modifiers such as polymaleic and polyacrylic acids or phosphonates. The scale formed tends to stay suspended long enough to be removed by either the blowdown or a filtration system.

The tendency for biological activity and fouling can be most effectively controlled by chlorination. Chlorine is usually added as a shock dose at night. It can be added as chlorine or as hypochlorite depending upon the size of the system. The hypochlorite should be sodium (Javex) as opposed to calcium (HTH) as the calcium would add to the system's scaling potential. Alternatively, a number of proprietary biocides can be used. These include isothiazalones, carbamates and quaternary products. Unlike chlorine, which oxidizes cell walls, the use of the proprietary products can lead to the development of an organism that adapts to the biocide. It is common to use one biocide and periodically alternate it with a second to kill off any bacteria that may have adapted.

The overall treatment program would include product formulations to cover all three areas and would be accompanied with a daily testing program to measure its effectiveness. It must be pointed out that as the operation of the tower leads to accumulations of contaminants in the water, good control of these materials can prevent severe corrosion or fouling of the heat-exchange surfaces. Four approaches can be taken to ensure adequate control:

1. Increase bleedoff to remove solids and prevent their concentrations from going too high. Unfortunately this approach also increases the quantities of water and treatment products used and tends not to be cost effective.

2. Utilize heavier dosages of treatment products to prevent deposition possibly with the incorporation of an acid-feed system to keep the carbonate equilibrium system in the more soluble bicarbonate form. This approach can be very costly and is counter to good environmental practice.

3. Provide filtration either on the basis of full flow or a side stream to remove the impurities as they collect and prevent their overconcentration. This is the preferred approach as it can maintain a clean system and thus tends to avoid or at least reduce the long-term fouling of heat transfer surfaces. It also does not add to the environmental load produced by the system.

4. Soften the water to reduce the level of hardness-forming salts to minimize the scaling potential.

The following table compares water and chemical costs with the once-through system. To establish a single basis for comparison, 3.5 cycles of concentration was selected. This value is typical of many HVAC systems. Water usage has been reduced to 1.2 percent of that required for once through cooling. The water is present longer and adaptable to better and more expensive chemical treatment programs.

WATER AND CHEMICAL REQUIREMENTS: OPEN-RECIRCULATING			
Evaporation	0.8%	153 usgpm	
Drift	0.1	20	
Bleedoff	0.2	44	
Makeup rate	1.2%	217 usgpm	
		0.3 million usg/day	
Time for 20,000 usg makeup		92 min	
Typical treatment program		daily	annual
inhibitor	@ 150 mg/kg	52 kg	19,160 kg
	@ $4.00/kg	$210	$76,630
proprietary biocide	@ 50 mg/kg	13 kg	4,920 kg
	@ $5.00/kg	$67	$24,580

assumptions: total volume 250,000 usg
operation at 3.5 COC

2.3 CLOSED-RECIRCULATING SYSTEMS

In a tight system with only a small bit of leakage (*eg.* from pump seals or valve packing), water may reside for many months. Water may be used both for heating as well as cooling. Often in building HVAC systems, the same system is used with either the heaters or chillers valved in depending upon the weather.

Treatment of closed systems can be relatively simple. As there is no evaporation, the scale-forming constituents of the water can't overconcentrate, so no treatment is required for this aspect. Corrosion inhibitors available range from relatively simple reducing agents to complex proprietary formulations. Most of the products are capable of operating over the entire range of temperatures from chilled-water cooling through to hot-water heating although some specific applications such as ice making may require special products. Typically for HVAC applications, the products are based upon:

a. **Hydrazine** or one of the substitutes which can act both as an oxygen scavenger and as a reducing agent to passivate metal surfaces. Iron forms a protective magnetite surface that resists further attack and remains stable for years. Hydrazine adds no solid material nor ionic material to the system. An alternative oxygen scavenger, sodium sulfite, has also been used for this purpose. It is a poor choice as it contributes ionic solids to the system and is able to passivate metal surfaces only at elevated temperatures.

b. A **nitrite/borate** formulation is the most common inhibitor used. Some of the newer products are now based upon nitrite/molybdate or molybdate/organic formulations. The main mechanism is as an anodic inhibitor to form a gamma-iron oxide film. It is imperative with this type of product to have enough. If the concentration is low, there will be areas that are unprotected. These sites will show severe pitting. Typical dosages will be in the order of 1,000 mg/kg as nitrite. This is approaching the limits of solubility. Any place where leakage occurs (*eg.* pump seals) will end up with heavy deposition. If this is a moving part (and it will be with a pump seal) severe wear will occur leading to leakage. Another problem with this product is that a specialized bacterium *Nitrobacter agilis* can devour the product and usually with no warning. Periodic biological testing and biocide additions may be required. The newer formulations using molybdates along with the nitrite or organics can operate at the 100-200 mg/kg range and thus reduce the wear problems.

As the retention time is long, solids formed within the system will have no place to go, but to deposit on the heat transfer surfaces. To prevent this the use of small side-stream filters is recommended. Typically they should handle 3-5 percent of the flow.

When these systems are used for both heating and cooling, dead legs are established when the heating or cooling seasons begin and the other portion is isolated. This is best overcome with some limited degree of circulation rather than leaving the system stagnant.

Comparison with once-through and open-recirculating systems, shows much reduced water usage and chemical costs.

WATER AND CHEMICAL REQUIREMENTS: CLOSED-RECIRCULATING		
Makeup rate	0.04	usgpm
	55	usg/day
Time for 20,000 usg makeup	365	days
Typical treatment program		annual
nitrite molybdate @ 100 mg/kg		8 kg
@ $4.00/kg		$30

assumption: total system volume turnover once/year

2.4 CONSERVING ENERGY IN HVAC SYSTEMS

This section looks at methods where energy can be saved in HVAC systems. Not all will be practical at any particular application. Some, involving equipment installation, may be practical for a new application, but not adapted to a plant retrofit.

Condenser-Water System

The condenser water circuit must have adequate cooling or the efficiency of the refrigeration equipment will fall. CARRIER[2], in their **Water Conditioning** manual, indicate just how sensitive this equipment is to cleanliness. Using values from their manual and existing electrical energy rates, it can be shown that even light fouling of the condenser tubes can increase the annual electrical cost to operate a 1,000 ton air conditioner by about $10,000.

The objective in any energy conservation program must be related to the condenser cleanliness. If it can be kept clean, the maximum efficiency can be obtained. As the condenser fouls, the cost for cooling will increase dramatically. Several methods are recommended starting with the least expensive.

2 *Carrier system design manual, part 5 - water conditioning* published by Carrier Air Conditioning Company, Syracuse, N.Y., (1972).

Biological Monitoring

The major source of fouling in open systems associated with HVAC applications is biofouling. A major contributor to biofouling is the growth of algae. To grow, they need light. Most towers have open decks (usually an economic decision) which are an excellent place for algae to flourish. A cover should be installed to minimize the effects of sunlight. This can usually be done quite economically using plywood.

Microbiological growth can get out of control rapidly, especially during warm periods with high pollen counts. No control is available without monitoring. Regular testing must be performed to measure the level of microbiological growth. The most reliable indicators are the simple "dip-stick" type cultures on which the bacteria and other species are allowed to grow over a controlled 24 - 48 hour period. The number of colonies is then assessed by comparing the appearance of the slide with a reference chart. Accuracy is not high, but is adequate to evaluate the degree of control and the actions required.

EVALUATION OF MICROBIOLOGICAL COLONY COUNTS

colonies/mL	*evaluation*
below 10,000	*excellent control*
10,000 – 100,000	*good control*
100,000 – 200,000	*adequate control*
200,000 – 500,000	*improvement needed*
500,000 – 999,999	*action required*
above 1,000,000	*immediate action required*

Additional biocides can be added whenever needed to ensure a low colony count. By maintaining a low colony count, the probability of biofouling is minimized.

Location of Bleedoff

An additional source of energy recovery can come from the location of the bleedoff line. It is frequently from the cooling tower sump. This is cooled water. Taking it from the warm return line has great advantages. Less flow is needed to do the same cooling and the tower can become more efficient as this water used for bleedoff does not require cooling. For a tower operating at 3.5 cycles of concentration, the savings in energy is about 1 percent of the total heat load. For a 1,000 ton air conditioning unit, the savings is about 10 tons or the equivalent of cooling 10,000 square feet of floor space.

Filtration

A cooling tower also functions as a spray washer for outside air. Debris ranging from dead birds through to sand from sand blasting in the neighbourhood will end up in the tower water. To prevent this, it is necessary to remove this material.

The dispersant, which is part of any program, keeps smaller particles in suspension long enough for them to be removed by the bleedoff system. These small particles will do little harm as long as they are in suspension. It is the larger debris that is likely to settle in a region of low flow and perhaps block the flow to a heat-exchanger tube or perhaps damage a pump impeller.

To maintain system cleanliness, it is vital that this material be removed and kept from doing harm. The standard technique has been to install a side-stream filter that carries about 5 percent of the total flow. Usually these are sand (for bigger systems) or removable cartridge (for smaller systems) filters. The logic is that they are efficient filters and will remove the fine particles with high efficiency. The problem with this thinking is that at a typical 5 percent of the flow it takes almost 12 hours for the entire system volume to pass through it. In that period, most of the settling will have occurred and the harm is done.

It may make more sense, in some applications, to utilize a less efficient filter with full flow capabilities. There are two main categories: the self backwashing

strainer and the centrifugal separator. While they can't do as much with particles below 100 micrometres, they can effectively remove those that are larger. The chemical treatment will look after the small ones. These units can treat the entire system every 10-15 minutes.

In the ideal situation, both could be installed to provide a superior grade of water.

Several industrial towers have made use of a side-stream clarifier that both softens the water and settles the particulate material. It is effective, but has the same problem, however, that only a small portion of the flow can be treated with a reasonable size of unit.

Reducing the Potential for Scale Formation

The temperature rise across HVAC equipment tends to be low. As long as the number of cycles of concentration is kept within the prescribed range for the chosen water-treatment program, there may be little scaling tendency. Each time measurements of water quality are made, the number of cycles should also be calculated and recorded. This is most commonly done on the basis of chlorides.

$$COC = \frac{[Cl] \text{ in tower}}{[Cl] \text{ in makeup}}$$

The main control parameter for the tower should be the number of cycles of concentration or COC. Optimization of the COC will significantly economize on the use of water. Going from the common 3.0-3.5 level up to about 5 COC will result in a 20 percent reduction in water requirements. Above this there is a diminishing return. The operation of most towers used in HVAC applications tends to be self-limiting at about 5-8 COC with the bleedoff valve closed. This is a safe operating condition providing the tower is equipped with a filter and using softened water makeup.

The potential for scaling is greatly reduced by softening the water entering the system. In an area such as Toronto, where the raw water hardness is 140 mg/kg

as $CaCO_3$, few systems utilize softening. Only a few kilometres away, where well waters are used, many systems use softeners. Softened water permits much higher cycling of the tower with a reduced treatment dosage and almost totally guarantees that scaling will not occur if the number of cycles is controlled. There will also be a much reduced consumption of both water and products due to the reduced bleedoff. Some degree of treatment must be retained for scaling as any leakage through the softeners concentrates as the number of cycles increases.

Alternatively, the potential for scaling can also be reduced by the addition of acid to the recirculating water. While this approach may appear to be relatively simple and inexpensive, most smaller plants that use it have run into component damage problems due to overfeed of the acid. If used, it is imperative that an adequate control system be included as part of the package.

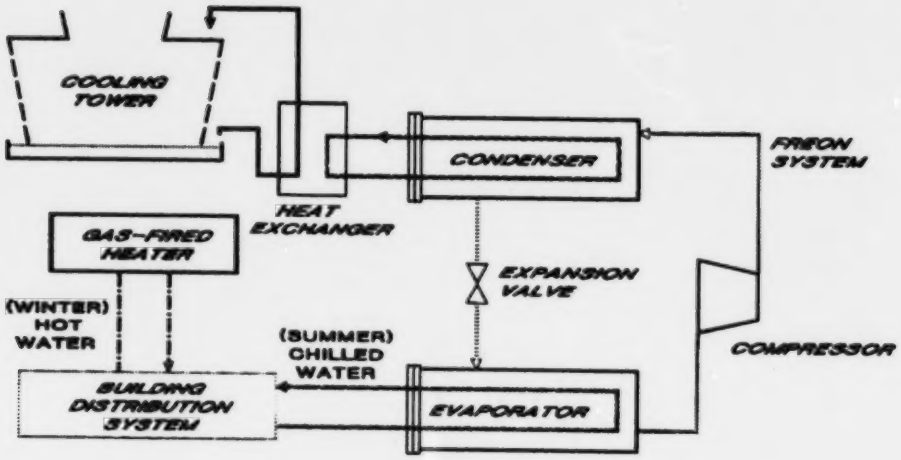
Isolation Between System Components

There has been almost no move toward isolating the tower and condenser systems. The addition of a plate and frame heat exchanger in the system will enable operation of the condenser water system as a closed system which is unlikely to ever foul. The open system will now be much smaller and less expensive to treat. With the small head required, the piping can be made of PVC which, when connected to the stainless steel heat-exchanger piping, will require a minimal type program.

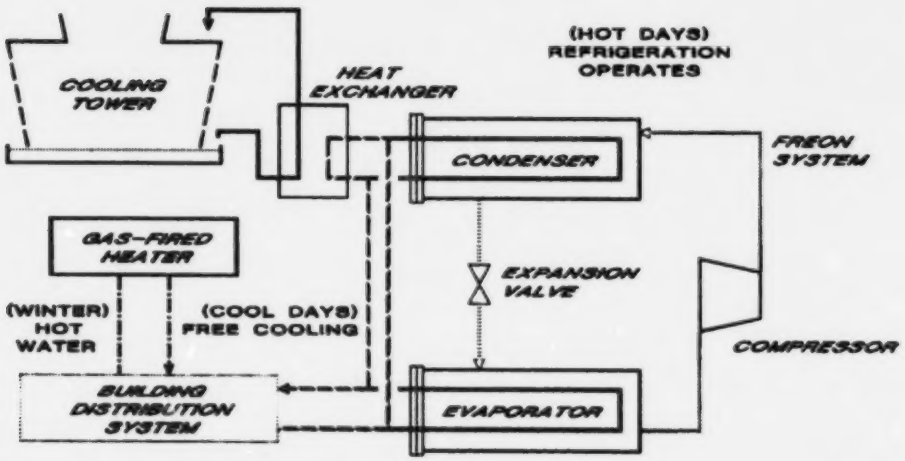
While this type of arrangement almost guarantees that the condenser tubes will not be fouled, there is an energy cost associated with the insertion of the heat exchanger plus the operation of an additional pumped circuit.

Free Cooling

The isolated system can be further modified by adding a few valves to make an effective **free cooling** system when days are not too hot, but the building still requires heat rejection. By directly interconnecting the condenser system into the building distribution system, the tower can supply adequate cooling for the chilled water system directly without the need for running the compressor. As both sys-



BUILDING HVAC WATER SYSTEMS WITH
TOWER ISOLATED BY HEAT EXCHANGER



BUILDING HVAC WATER SYSTEMS WITH
FREE COOLING OPTION FOR COOL DAYS

tems are on closed loops, they both have the same water treatment program and there is no problem with mixing.

Free-cooling systems, where the condenser water is an open system, can be difficult to treat due to difficulties when the systems mix. It may not easy to obtain a reasonable and economical chemical treatment program compatible with both. The closed system can become fouled and lose efficiency. This problem is best eliminated by installing the heat exchanger between the closed and open circuits.

Chilled and Hot Water Systems

The closed circuits are relatively easy to operate and control. The biggest problem will be losses of heated or chilled water if the system has leaks. The major source of leakage is from seals and glands. The most common product used is nitrite/borate. There is a never ending controversy as to whether nitrite is the cause of seal failure.

Packed seals must leak to get the required cooling and lubrication. As a nitrite solution leaks, the water evaporates and the crystals stay behind to score the metal shaft. While this occurs with many products, it is more evident because the required level of product is high (>2,000 mg/kg total dissolved solids) and the crystals tend to be hard. This product does not cause the leak, but it will aggravate a leak and make it bigger. If seal maintenance is a problem, then an alternative product should be used. In addition, filtration should be provided to remove particulates from the system. As this is a closed system without bleedoff, the time scale tends to favour the use of side stream filters that remove the finest particulates.

Often chilled water and hot water circuits are interconnected through the same distribution system. This should cause no difficulty except in dead legs that may be filled (or perhaps partially filled) for extended periods of time each year. Severe corrosion can occur in these regions. Every effort must be made to provide some mechanism to provide a limited replacement from time to time with treated water. The other option is totally draining the system and allowing it to dry.

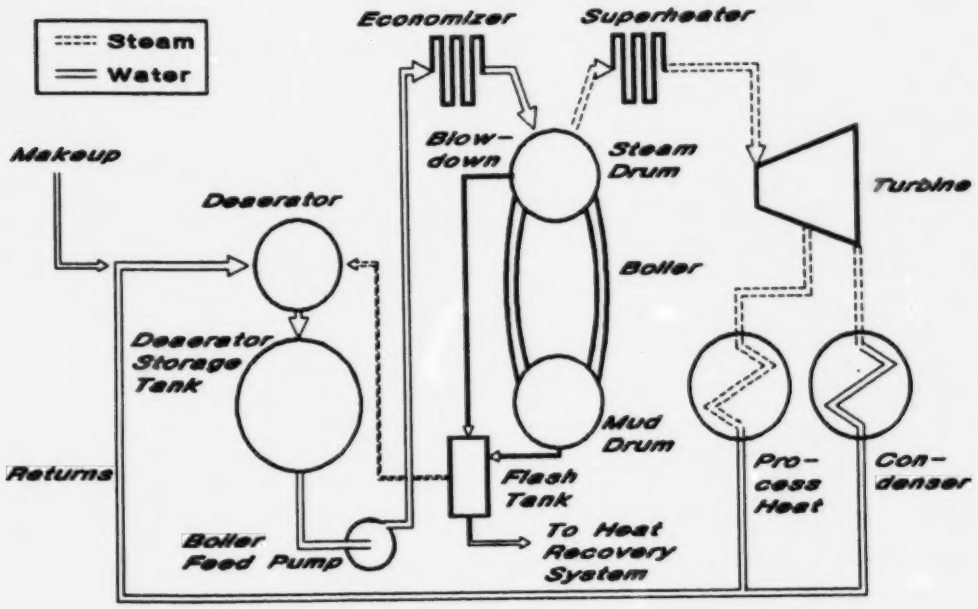
3

IMPROVING ENERGY EFFICIENCY IN BOILER SYSTEMS

BOILERS come in many sizes and varieties and may use coal, oil, gas, nuclear or even garbage as the energy source. Some operate at relatively low pressures, others at high pressures. It is not the intent to look at boiler designs, but the basics common to all designs. In all boilers:

a. Steam is relatively free of solids; therefore, the solids must concentrate in the boiler water.

b. The steam may heat a process; it may be superheated, turn a turbine or any of several other variations. Condensed steam is pure water and can be returned to the process without significantly adding solids.



UTILITY–BOILER WATER CYCLE

Successful operation of a boiler water system will be determined by the *quality of the water feeding the boiler.* This quality is established by external treatment (usually determined by choice of hardware ahead of the boiler) and the proportion of condensed steam that can be returned to the boiler as feedwater. Whatever materials pass the external treatment system, must be treated by the internal treatment program (usually determined by a choice of products added to the water either on the way to or once inside the boiler).

Over the years, the American Boiler Manufacturers Association as well as a number of other organizations have established various sets of **consensus** guidelines for water quality in boilers of different designs operating in the various pressure ranges. Most water treatment programs have developed around these guidelines. Basically the concept is to tighten up water quality as the operating pressure goes up. Newer boilers tend to be more critical in their design parameters to improve efficiency and need water quality at the better end of the scale. As a rough summary:

a. Low pressure boilers can operate with minimal water quality, but require an extensive internal-treatment program to keep them clean.

b. High pressure boilers are more sensitive to impurities and should operate with better feedwater quality and a less extensive internal-treatment program.

Many guidelines have been published recommending both internal and external treatment requirements *vs* pressure. It is not the intent to do the same here as it is the opinion of the author that many boilers receive inappropriate treatment from attempts to adhere to these guidelines. There is a failure, on the part of many designers and operators, to recognize that these guidelines tend to give **minimal** requirements which are not necessarily the optimal requirements.

Striving to meet these guidelines may reduce "front-end" *ie.* capital costs for a boiler installation, but only at the expense of increasing operating costs. The major cost to consider is **energy** which can vary considerably with the feedwater

quality. Chemical treatment costs do not show this same wide variation and should only be looked at after the energy considerations are evaluated.

3.1 BOILER WATER TREATMENT REQUIREMENTS

Successful chemical treatment of water in a boiler has just three fundamental requirements:

1. Removal of oxygen to minimize pitting corrosion.

2. An elevated pH range to minimize general corrosion.

3. An effective system to prevent the ingress and concentration of dissolved and suspended solids.

All other requirements forced upon the system are needed to cope with impurities (and that term could very well include the treatment products) in the boiler feedwater.

Having said the above, the obvious implication is that feedwater quality is important to all boilers. A better interpretation of the various guidelines might be that all boilers require the best quality feedwater that can be provided but lower-pressure boilers have a higher tolerance if this requirement is not fully achieved.

Oxygen Control

Oxygen removal from the boiler feedwater can be accomplished both with hardware and products.

a. The main thrust should be through the use of a **deaerator** or **deaerating heater**. Feedwater is sprayed into the deaerator vessel where it contacts a flow of steam. The steam heats the water and drives off the dissolved gases. The steam and gases are vented to the atmosphere, hopefully through some form of energy recovery system. The heated water then moves to the storage tank until needed by the boiler. Typically, oxygen can be reduced to the 20 microgram/kg range or lower.

As the water is fed to the storage tank, it is chemically treated to remove any residual oxygen. Chemical treatment is practical only after the bulk of the oxygen has been removed "mechanically" by the deaerator. If used earlier, costs would be prohibitive.

b. There are a number of oxygen scavengers on the market. These fit into two categories: hydrazine (and its substitutes) and sulfites.

Hydrazine can act both as an oxygen scavenger and a reducing agent to passivate metal surfaces. It combines with oxygen producing nitrogen and water:

$$N_2H_4 + O_2 \rightarrow 2N_2 + 2H_2O$$

These products have no further effect on the system. The iron forms a protective magnetite (Fe_3O_4) surface that resists further attack and remains stable for years. Often a catalyst is added to accelerate the oxygen scavenging rate. Hydrazine adds little solid or ionic material to the system. It is ideal for the job, but has come under attack due to various, as yet unsubstantiated, claims about its carcinogenic nature. As a result, various alternative products have been brought to the market as substitutes. ...in fact, they are often sold as being **hydrazine substitutes**. Hydrazine has not been proven to be a carcinogen. There is even some reported use of hydrazine compounds for **the treatment of cancer symptoms**. Some of the substitutes have not been fully investigated and may also be of a potential carcinogenic or toxic nature. Most of the substitutes cost about 10-20 percent more on a per-kg basis than hydrazine, but may require dosages as much as 5-10 times higher as they are heavier molecules. The comparison must be made on the basis of the mass of one mole. By a coincidence the mass of one mole of oxygen and hydrazine are equal, meaning that 1.0 mg/kg of hydrazine reacts with 1.0 mg/kg of oxygen.

Sodium sulfite has also been used. Compared to hydrazine, it contributes ionic solids to the system and is able to passivate metal surfaces only at elevated temperatures.

$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$$

The reaction product is an ionic salt and thus it also contributes to boiler conductivity. Under appropriate conditions, a sulfate-containing deposit could be formed. The dosage, on a mass ratio basis, requires 8 mg/kg for each of oxygen. Sodium sulfite may not react quickly enough to adequately scavenge oxygen from boiler feedwater. The rate of reaction is considerably enhanced by the addition of a small quantity of a cobalt salt as a catalyst. The catalytic action can be deactivated by several products commonly used for boiler treatment. Addition of catalyzed sulfite and any phosphate product from the same addition tank will, as an example, result in deactivation of the catalyst. Sodium sulfite is available as an open-market commodity. The catalyzed sodium sulfite is a blended product and must be purchased at a much higher cost.

There is, at present, a preference in many locations to use sodium sulfite over hydrazine because of lower costs and greater safety. Neither of these is totally valid. There are no reported deaths due to hydrazine exposure in spite of the perceived risk associated with its use. There are several each year, in Canada, attributed to sodium sulfite. It is a common additive to foods as a preservative. Meat keeps looking red and lettuce green. For this reason sulfite products used in the food industry **for boiler water treatment** must contain an additive that prevents them from making foods look better than they really are. Lignin derivatives are commonly used. Sulfites can trigger severe allergic reactions, **which can result in death**, in some people with asthmatic and other conditions that make them particularly sensitive.

pH Control

A number of products can be used to raise the pH. The choice is usually dictated by considerations such as steam-line or condensate-line treatment or scale control. The basic list of products contains:

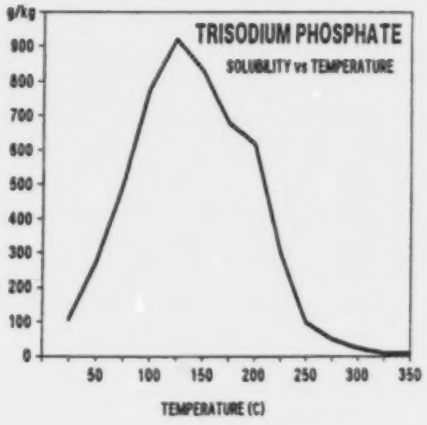
a. **Caustic soda (NaOH)**: This product contains no buffering capacity and can make a very rapid, almost uncontrolled, change if there are any problems

with the addition equipment. It is a solid and can concentrate at a boiling surface. Although treatment levels may be in the mg/kg range, local concentrations at the boiling surface can be as high as 10-20 percent. There is a possibility of stress corrosion cracking (caustic embrittlement) or caustic gouging of the metal.

b. **Sodium phosphate**: This product may be used in the form of one or a combination of disodium phosphate (Na_2PO_4) or trisodium phosphate (Na_3PO_4). Phosphates are present both to control pH and also to control scaling as discussed in the next section. Phosphates are solids and will concentrate at boiling surfaces. They have a very complex phase diagram which indicates several problems.

Solubility of trisodium phosphate increases up to 117°C then rapidly drops as various hydrated phosphates precipitate from solution leading to **phosphate hideout** on hot surfaces. Water analyses may continue to show low phosphate as deposits form from local excesses.

Free caustic soda or phosphoric acid can form locally under certain conditions. To prevent this, precise control is required to ensure that these products do not get out of control. The most common treatment is coordinated phosphate which sets a required sodium-to-phosphate ratio of 2.8:1 to prevent problems.



c. **Ammonia, Morpholine and Cyclohexylamine**: These products are volatile amines and present no problem with solids. They also carry through with the steam to protect the steam and condensate portion of the system. Volatile amines are part of all of the above programs because carbon dioxide may be

present in all steam and condensate systems as a result of breakdown of carbonates and the various organic products that may be present, and will definitely be present, if the water is not adequately treated before the boilers. The amine will protect against attack by the carbon dioxide which is usually evident as a thinning at the bottom of condensate piping. The choice of products is based upon such factors as cost, pressure, length of steam distribution lines and whether or not steam could contact food. Most commonly it is a blend of morpholine, to protect at shorter distances, and cyclohexylamine, to protect the longer lines.

Solids Control

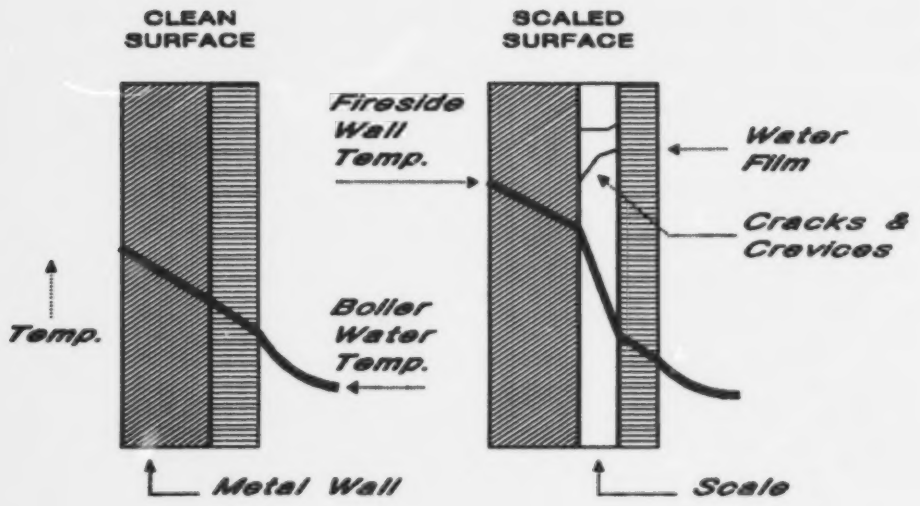
There are three actions that can be taken to provide solids control in a boiler system. Impurities must be removed before the water enters the boiler or a treatment program must be instituted to control them once they are inside.

a. Treat the water externally to remove dissolved and/or suspended solids before they reach the boiler.

b. Drain a small portion of the **hot** water from the boiler to prevent the levels of solids from getting too high (**blowdown**) or

c. Institute an internal chemical treatment program to modify the solids into a form which can be removed by the blowdown system as opposed to forming a scale on the tube surfaces.

Solids, once in the boiler, will concentrate particularly at those surfaces with the highest heat transfer. This concentration can lead to local deposits and loss of heat transfer. There have been many measurements of the insulating properties of boiler scale and the extra fuel required to deliver the same load. As the heat will usually find an alternative route to make its way into the water to produce steam, the problem here will not be one of energy conservation. Local hot spots may develop and individual tubes will be overstressed until they fail during operation.



TEMPERATURE PROFILE ACROSS SCALED BOILER TUBE

3.2 BOILER WATER TREATMENT PROGRAMS

There are a large number of programs designed to control scaling in boilers as well as corrosion both within the boiler and along the steam and condensate pipework. These fit into several groups.

a. **All volatile treatment** or **AVT** is the simplest treatment. Its use tends to be restricted to the big high pressure fossil and nuclear electrical generating plants. This treatment is based upon treating the water before it enters the boiler. No solids are added, just hydrazine and ammonia or a volatile amine. This treatment has no buffering capacity and **MUST** have the best quality demineralized water as makeup. Typically the water treatment plant will follow the cation and anion resins with a mixed bed polishing unit. In addition many of the plants will tend to have resin and or filter beds to polish the condensate. Returns tend to be high; usually around 98 percent or better.

b. **Coordinated phosphate** is the most common treatment. As discussed earlier, it sets a sodium-to-phosphate ratio of 2.8:1 to prevent forming free caustic soda. The objective of this program with respect to solids is to convert any hardness into a free-flowing phosphate sludge that can be removed by blowdown rather than depositing on the hot surfaces. Calcium forms calcium phosphate. With a boiler pH of about 10 or higher, this forms a mineral hydroxyapatite. With a proper sludge conditioner, this material will have the required properties. The program is relatively forgiving of poor control, unless there is excessive oil contamination or inadequate blowdown.

c. **Chelants** are used to solubilize the hardness and iron. Typical products are ethylenediaminetetraacetic acid, EDTA, and nitrilotriacetic acid, NTA. In addition, there will be thermal breakdown products, many of which are also chelants. By solubilizing the materials that would normally deposit, the boilers can be kept clean. The problem is that they are not forgiving products. Problems with feeding, in particular overfeeding, will remove metal from the boilers and lead to possible failure. The presence of oxygen leads to iron oxide formation. Under normal boiler conditions, this oxide can be made somewhat protective, but in the presence of chelant, it dissolves. Several well-known and respected water-treatment companies have had troubles with chelant programs. Now few of them actually push them. The use of chelants is best restricted to major plants with very tight control.

d. **Dispersant**-based programs have been around for many years and seem to go in and out of favour as they have a tendency to succeed in some locations, but not others. The inevitability of scale formation is accepted, but by using products such as polyacrylates and phosphonates, the crystals can be modified to a form that is not adherent and easily removed through blowdown.

Looking at the four options, AVT and Chelants lack the ability to forgive errors. Phosphate programs are good with reasonable control, but with poor control can form phosphate-containing deposits. Dispersant programs, where they succeed, can be forgiving and add no solids to the system.

It must also be remembered that boiler water control applies when the boiler is down, not just when it is operating. The ASME layup procedures call for an oxygen scavenger (typically sulfite or hydrazine at 200 mg/kg) and a base (typically sodium hydroxide, ammonia or one of the amines) to keep the pH above 10.0. The system should be full and provided with some circulation.

Is There a Best Boiler Treatment Program?

The preceeding summary of the various programs is short. Why? The reason is that you can go from plant to plant and find that each of them succeeds well and fails miserably depending upon the location. Individual plant operators will swear by (or at) individual water-treatment companies and their service representatives. When you sort through this, the picture that emerges is that each and every one of the programs listed can work well at various plants. The assortment of programs, suppliers and technical representatives is a smoke screen that hides the real reasons behind success and/or failure.

- **Personnel** make the biggest difference. The plant operates well only because there are people prepared to go to the effort of making it work.

- **Water quality** is the next major factor. The best designed and controlled plant is not going to function well when oil spills into the intake. Hardness can only deposit in the boilers if it gets into them.

- **Design** plays a very significant role. Often the water-treatment plant is incorrect or inadequate for the application. It is difficult to control oxygen without a deaerator.

3.3 CONSERVING ENERGY IN BOILER SYSTEMS

The objective now is to apply the above to conserving energy. Not all methods will be practical at all locations.

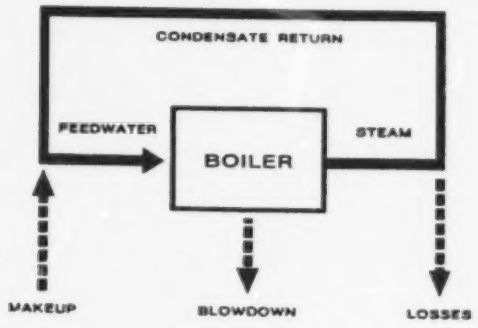
The major sources of energy loss in a boiler system are blowdown and steam/condensate losses. To track these down, it is necessary to have an indication

of the magnitude of these losses and how they change with respect to the operation of various pieces of hospital equipment in service at any time. Once there is a measure of the losses, they can be reduced by the appropriate means.

The method of reducing blowdown is to improve upon the feedwater quality. This can be done by upgrading the treatment method used and/or by recovering condensate.

System Mass Balance

To determine the various losses from the system, it is necessary to do a mass balance with respect to the operation of the boiler. As an example, the calculations will be made using numbers based upon a large hospital boiler producing 60,000 lb/hr of steam where because of plant design, 20 percent of the steam (*ie.* 12,000 lb/hr) is lost and the remaining 80 percent (*ie.* 48,000 lb/hr) is returned to the boiler as condensate. These flows are fixed by the system design.



BOILER MASS BALANCE

A number of simple relationships become apparent:

Feedwater flow = sum of makeup and returns: $F = MU + R$

Feedwater flow = sum of blowdown and steam.: $F = B + S$

Makeup replaces blowdown and losses: $MU = B + L$

Steam produced = sum of return and losses.: $S = R + L$

From these relationships, the following can be derived and will cover essentially all the calculations necessary to cover a boiler mass balance calculation.

Cycles of concentration can be evaluated relative to either feedwater or makeup concentration. A subscript indicates which and the square brackets refer to concentrations of a selected species that is measured. The most common species is chloride as it is easily measured and remains in solution in the boiler at operating temperatures. To make the necessary calculations, it is necessary to measure chlorides in four locations: the makeup, feedwater, blowdown (*ie.* in the boiler) and returns (*ie.* in the condensate).

$$COC_{MU} = \frac{[Cl]_B}{[Cl]_{MU}} \quad \text{and} \quad COC_F = \frac{[Cl]_B}{[Cl]_F}$$

The two are related by:

$$\frac{COC_{MU}}{COC_F} \times 100 = \%MU$$

Experience with a large number of boilers operating using the more conventional treatment systems indicates that most, with similar condensate return rates, tend to operate in the region of 10 cycles of concentration based upon feedwater composition. *ie.* the various species are 10 times more concentrated in the boiler than in the makeup.

The percentage of returns can then be related to the four chloride values measured:

$$\%R = 100 \times \frac{[Cl]_F - [Cl]_{MU}}{[Cl]_R - [Cl]_{MU}}$$

A few additional variations of the above equations relate:

MAKEUP to returns: $\%MU = 100 - \%R$

BLOWDOWN to feedwater flow and steaming rate: $B = F - S$

FEEDWATER to steaming rate and blowdown: $F = (100 \times S)/(100 - \%B)$

LOSSES to makeup and blowdown: $L = MU - B$

The above calculation is based upon measured levels of chloride in the boiler. It is also possible to calculate the blowdown requirements for a given species such as alkalinity or total dissolved solids as well as chloride. The difficulty is that unlike chloride, which is soluble, some of the species involved may not be adapted to direct measurement as they may be less soluble under boiler conditions. For a boiler feedwater containing 60 mg/kg total dissolved solids and 30 mg/kg of alkalinity operating to the ASME guideline of 3500 mg/kg of total dissolved solids and 600 mg/kg of alkalinity, the required blowdown for each of these species can be calculated.

B_x = [x in feed]/[x in ASME guideline - x in feed]

$B_{TDS} = 60/(3500 - 60) = 0.017$ ... x 100% = 1.7%

$B_{alk} = 30/600 - 30) = 0.053$ ... x 100% = 5.3%

Blowdown requirements for the boiler will be based upon the species with the highest blowdown rate, *ie.* in this case it will be the total dissolved solids.

Assuming that the boiler used for the mass balance calculation operates on Lake Ontario water, a mass balance of the system can be made. To illustrate the value of external treatment, the calculations will be done with various **front-end** pre-treatment equipment to see their influence.

If this is a typical hospital boiler operation in one of the large metropolitan areas of Southern Ontario, the makeup to the boiler will be softened. Lake Ontario contains 30 mg/kg of chloride, so **MU = 30** as softening has no influence on the chloride levels. Typical analyses may show 300 mg/kg in the boiler and 0.1 mg/kg or less in the condensate. The feedwater value would be 20 percent of the makeup value or 6.5 mg/kg. Taking these values and calculating, the following values are obtained:

$$COC_F = \frac{[Cl]_B}{[Cl]_F} = \frac{300}{6.5} = 46.2$$

$$COC_{MU} = \frac{[Cl]_B}{[Cl]_{MU}} = \frac{300}{30} = 10.0$$

ie. the solids concentrate to a level 46 times higher than their original concentration in the feedwater and 10 times their concentration in the makeup to the system. 10 mg/kg of an impurity in the water supply becomes 100 mg/kg in the boiler water. Likewise, to obtain 100 mg/kg of treatment product A, only the equivalent of 10 mg/kg must be fed to the system.

RETURNS $\%R = 100 \times [(30 - 6.5)/(30 - 0.1)] = 78.3\%$

MAKEUP $\%MU = 100 - \%R = 100 - 78.3$ .... or
$= (COC_{MU}/COC_F) \times 100 = (10.0/46.2) \times 100$
$= 21.7\%$

BLOWDOWN $\%B = \%MU/COC_{MU} = 21.7/10.0 = 2.17\%$

LOSSES $\%L = \%MU - \%B = 21.7 - 2.17 = 19.5\%$

The individual flows can then be calculated from the percentage values.

FEEDWATER $F = (S \times 100)/(100 - \%B)$
$= (60{,}000 \text{ lb/hr} \times 100)/(100 - 2.17)$
$= 61{,}300 \text{ lb/hr}$

MAKEUP $MU = 21.7\% \times 61{,}300 = 13{,}300 \text{ lb/hr}$

BLOWDOWN B = 2.17% x 61,300 = 1,330 lb/hr

RETURNS R = 78.3% x 61,300 = 48,000 lb/hr

LOSSES L = 19.5% x 61,300 = 12,000 lb/hr

As can be seen from this example, a very significant proportion of the energy can be lost. Once there is a means of measuring them, it is possible to track them down and do something about them.

The following page gives a listing for a BASIC program to calculate the mass balance described above. The version shown runs on an MS-DOS™ compatible system, but should operate on any other computer with little or no modification.

Reducing Losses Through Blowdown

There are three approaches to reducing blowdown energy losses.

1. automate the continuous blowdown

2. install a recovery system or

3. improve the quality of the boiler feedwater.

Automation of continuous blowdown

Where blowdown is manually controlled, there is a significant time delay between the boiler requiring blowdown and the measurements being made and actions taken. This delay can result in large spikes in the control which end up with higher blowdown than is actually required. By installing an analyzer, based upon conductivity, that continuously measures water quality and reacts to it, the spikes, in the control, can be minimized and the desired water quality achieved with less total blowdown. Estimates have been made that smoothing the control can reduce the total blowdown by somewhere between 15 and 25 percent depending upon the individual situation. The conductivity cell must receive a cooled sample. Simple systems are available for less than $1,000 for systems operating at 150 psi or less and somewhat higher for higher pressures. The use of one of these systems has

```
100 '*****************************************************************************
110 '
120 '    Boiler Treatment Calculations (hourly flows) - 1986-12-11
125 '    (C) 1986 by MARVIN SILBERT AND ASSOCIATES
130 '
140 '*****************************************************************************
150 CLS
160 PRINT"*****************************************************************************
********"
170 PRINT: PRINT" BOILER MATERIAL BALANCE    ";: LINE INPUT ID$
180 PRINT"*****************************************************************************
********"
190 PRINT: INPUT"lb of steam per hour  ";STM
200 INPUT"Cl in makeup          ";CLMU
210 INPUT"Cl in feedwater       ";CLFEED
220 INPUT"Cl in boiler water    ";CLBLR
230 INPUT"Cl in returns         ";CLRTN
240 COCM=CLBLR/CLMU: PRTN=((CLFEED-CLMU)/(CLRTN-CLMU))*100
250 PMU=100-PRTN: PBD=PMU/COCM
260 FEED=(STM*100)/(100-PBD)
270 RTN=(PRTN*FEED)/100: MU=FEED-RTN
280 BD=FEED-STM: LOSS=MU-BD: PLOSS=100*LOSS/FEED
290 COCF=(COCM*100)/PMU
300 PRINT
310 PRINT USING"COC based upon makeup    =#,###.#";COCM
320 PRINT USING"                feedwater =#,###.#";COCF
330 PRINT
340 PRINT USING"pounds/hour   feedwater  =##.##^^^^";FEED
350 PRINT USING"              returns    =##.##^^^^  as percent =###.#";RTN,PRTN

360 PRINT USING"              makeup     =##.##^^^^              =###.#";MU,PMU
370 PRINT USING"              blowdown   =##.##^^^^              =###.##";BD,PBD
380 PRINT USING"              losses     =##.##^^^^              =###.#";LOSS,PLO
SS
390 PRINT
400 PRINT"*****************************************************************************
********"
410 PRINT"[N]ew data or [E]xit"
420 X$=INKEY$: IF X$="" THEN 420
430 IF X$="n" OR X$="N" THEN 150
440 END
```

```
*****************************************************************************

 BOILER MATERIAL BALANCE    Sample Boiler Calculation
*****************************************************************************

lb of steam per hour  ? 60000
Cl in makeup          ? 30
Cl in feedwater       ? 6.5
Cl in boiler water    ? 300
Cl in returns         ? 0.1

COC based upon makeup    =   10.0
               feedwater =   46.7

pounds/hour   feedwater  = 6.13E+04
              returns    = 4.82E+04  as percent = 78.6
              makeup     = 1.31E+04             = 21.4
              blowdown   = 1.31E+03             =  2.14
              losses     = 1.18E+04             = 19.3

*****************************************************************************
[N]ew data or [E]xit
```

the added advantage of providing the operator with a continuous indication of the level of total dissolved solids in the boiler.

Blowdown energy recovery

Blowdown energy recovery systems consist of two parts. First a flash tank to allow the hot water to flash to steam. This steam is usually vented to the deaerator where its energy is recovered. If the remaining hot water goes to the drain through a heat exchanger it can release some of the remaining heat to incoming feedwater. The price of the equipment is dependent upon the blowdown flow. Installation may also require extensive work with the boiler shutdown. This may not be acceptable to the operation of the hospital.

If the blowdown flow can be minimized, then the amount of heat to be recovered can be reduced and the need may be for nothing more than a simple flash tank. Improvements to water quality would pay back more than the recovery system.

Improved external water treatment

Softened water still has some tendency to scale. Some calcium and magnesium will make it past the resin. The resins do not touch the bicarbonates (alkalinity) which can then precipitate in the boilers and **produce the carbon dioxide that consumes the amines.** To further reduce the potential for scaling there are a number of techniques for dealkalizing the water. If these are applied to the preceeding example:

a. **Improved softener operation:** Most softeners operate on the basis of throughput. This is usually established either by design or by actual measurement during the early commissioning of the system. The actual capacity of the softener often changes over long periods of operation as a result of many factors including resin fouling, loss or deterioration of the resin, variations in flow rates or possibly a change in water quality. A loss of capacity may result in leakage of hardness at the end of each run. To ensure minimal leakage, the operation of the softener must, from time to time, be

checked and optimized to ensure that the expected water quality is being met.

b. **Softened and dealkalized water**: Dealkalization may be accomplished by several methods. One of the most common is through the use of a chloride-form ion exchange resin. The chloride substitutes for the alkalinity, sulfates and other anions. Typically, chloride exiting a dealkalizer, using the same water as the example, will rise to about 120 mg/kg. Setting the same 300 mg/kg limit, the mass balance, for the above example, can be recalculated and shows a significant increase in the required blowdown from 2.17 percent up to 12.0 percent. This approach to improving water quality is in use at a number of hospitals. While it may improve the operation with respect to scaling potential, it does not conserve blowdown energy as it does not reduce the total dissolved solids carried in the boiler.

Alternative forms of dealkalization using ion-exchange resin in the hydrogen form may remove alkalinity, but do not remove the chloride. They may improve the overall situation by significantly reducing the total dissolved solids carried in the boiler and allow reduced blowdown.

c. **Reverse Osmosis and/or Demineralization**: These processes remove essentially all of the dissolved species. At the smaller makeup volumes needed by hospitals, reverse osmosis appears to be less expensive with respect to capital. It also avoids the use of hazardous regenerants. It does, however, consume a significant quantity of water (approximately 30-50% more) and reject a low quality water as waste. This water could be reused in other hospital systems such as flushing toilets, etc. where high quality is not needed.

Typically a reverse osmosis unit rejects 98 percent of the impurities from the water. Assuming a 1.0 mg/kg chloride residual passing the treatment and calculating the mass balance, keeping the same 300 mg/kg chloride limit, the blowdown is reduced to almost nothing. As chloride is both the easiest to measure and the most likely species to pass through the purification system, it is not a comparison of equal quality waters. The water that passes through an RO/DI system may contain some sodium and chloride, but essentially none of the scale forming species.

d. **Recovering condensate**: Condensate is high quality water. The more that returns to the boiler, the less makeup will be required and hence the less blowdown that will be required. In addition, if the condensate is hot, there will be less energy required to boil it.

The implication is that a very significant energy savings can be realized with better quality makeup to the boiler. Blowdown is hot water; when it is lost, so also is the energy required to heat it. The extent of heat recovery varies from plant to plant. Typically 30 percent or more is lost. A plant this size, will have an annual fuel bill exceeding $2.0 million. Taking a 30 percent loss as being typical and multiplying this by the annual fuel bill, a cost can be assigned to blowdown.

Improved Oxygen Control

One product that is commonly misapplied is sodium sulfite. It is a relatively inexpensive material and as such not really noticed, but a dollar value can be assigned to its contribution to the overall blowdown. Typically with a softened water supply, 5 percent of the blowdown is from the sulfite if it is dosed at the 30-50 mg/kg range normally recommended. It can also lead toward sulfate based deposits on the boiler tubes.

ENERGY LOST THROUGH BLOWDOWN

TREATMENT	*percent*	*lb/hr*	*$,000*
Softened	*2.17*	*1,330*	*21.7*
Cl dealkalized	*12.0*	*8,180*	*120*
Reverse Osmosis Demineralization	*0.07*	*40*	*0.7*

assumptions:
1. lost assumes 50x recovery
2. $ based on annual $2 million fuel bill
3. max Cl in boiler = 300 mg/kg

Sulfite is there to scavenge oxygen. For each 1.0 mg/kg of oxygen, 8.0 mg/kg of sodium sulfite is required. If the plant has a **well operating deaerator**, typical

oxygen levels leaving it are less than 0.02 mg/kg. The level of sodium sulfite needed would then be 0.16 mg/kg plus a safety factor. 1.0 mg/kg is more than adequate, yet the recommendation is always 30-50 mg/kg.

The need is for a maintenance program aimed at optimizing the use of the deaerator rather than the use of products to ensure adequate oxygen control. This is of particular importance with coil-tube boilers which can be almost shut down then fired up on demand to meet needs. Their design could be improved with a recirculation line that permits better control of the water.

High levels of sulfite are recommended in order to provide a large and easily measured excess for safety. The real control parameter should be the oxygen rather than the sulfite. Rarely do plants do a measurement of dissolved oxygen. The analysis can be tricky and give misleading results. The important factor to look at here is that the results will either be correct or high; never low, because any error comes from air inleakage. There are simple test kits and easily installed on-line instrumentation. Doing regular dissolved oxygen analyses can reduce the excess of sulfite carried and also give an insight into the operation of the deaerator.

Hydrazine, prior to the latest scare, was a preferred oxygen scavenger. Being a weak base and having nitrogen and water as the only products formed, it did not contribute to the blowdown requirements of the boiler. Some of the hydrazine substitutes will also operate with lower blowdown requirements.

Product Dosage

Reduction in blowdown will translate into reduced product consumption. Typically at 4-5 percent blowdown, the products used to control pH and condition sludge must be replaced essentially every day. At 0.5 percent blowdown, the period is extended to roughly one week meaning that the requirements for many products may be reduced by as much as a factor of ten. With less makeup or better makeup, there will be less alkalinity brought into the boiler. This means less carbon dioxide is produced and the requirements for neutralizing amines will be reduced.

Should it become difficult to justify improvements to water quality entirely on the basis of energy saved, the cost of the chemical products saved may help to provide the needed justification .

4

MONITORING AND CONTROL TO MAINTAIN WATER QUALITY

4.1 WHY IS IT NECESSARY TO LOOK DEEPER?

The traditional water-treatment vendor approach begins with the establishment of a program based upon a number of formulated products, often identified only by a number giving no indication of the content. The vendor establishes a set of control parameters based upon experience. Plant operators are required to routinely monitor water quality to confirm that the products are dosed as specified. These analyses are **recorded and filed mainly as proof that the operator was doing the job properly**. They become important only in cases of serious malfunction or extended down time. Usually the daily digestion and summary of information from the various tests is done only as required to avoid the obvious in a normally operating plant. This data, which is usually then filed and ignored, could provide useful historical data and information that can be used for process optimization and troubleshooting, but only if:

1. enough data is available for a reasonable and secure estimate of overall conditions

2. the data is unbiased both with respect to time and operator

3. no important information (*ie.* a critical parameter or time period) is missing

The criteria above generate two obvious questions: **What kinds of data are important enough to collect? If this data is important enough to collect, what should be done with it?** Data on its own is meaningless. The use of appropriate data-reduction techniques can provide benefits in reduced maintenance, lower operating and chemical costs, and reduced unscheduled downtime. To determine what kinds of data are important, one needs to really understand the process. The following questions need to be answered:

1. What systems (or system components) need protection? .... and from what? Which components are critical?

2. Which parameters indicate problems? *eg.* A low value for a sulfite analysis, in boiler feedwater, means nothing as sulfite should never be a control parameter. **It is common to load the system with sulfite rather than make the effort to look at the dissolved oxygen which is the important parameter. (As a consequence, high sulfite means extra blowdown which means lost energy and higher product revenue.)**

3. What is the relationship between the actual values of these parameters and those measured? To get a sample from a boiler, it must be cooled, depressurized and transported through sample lines and valves. These all take their toll on the sample and then we make our measurements at a temperature much lower than the boiler operating temperature.

4. What needs to be measured to ensure adequate knowledge of the system performance? ..... and at what frequency?

5. Can data be collected in such a fashion that a quick glance at the logs will show what has happened over the last day, week, month or year?

6. Does or should the system hardware actually permit operation within the established specifications? .... Is the existing hardware adequate or should a change be evaluated?

Perhaps the most obvious to many are the questions based upon the products and program itself:

7. A major steam generating facility is a dynamic chemical system. Most programs are based upon steady-state operation and while effective much of the time, there are times when conditions are not adequate. Does the program compensate for such factors as changing loads. Failure to compensate can lead to costly repairs and/or replacements.

8. Is there a best treatment program for a plant? **Does it utilize all of the products and technology available in the marketplace** or is it just based upon a single supplier's product line? **Could a hardware change provide a better payback than a product change?**

Proper attention to water analyses is as important a part of preventive maintenance as are the various other obvious electrical and mechanical aspects. Bad operating practices are hard to prove and blame is impossible to pinpoint. The operators, with their clipboards will have done their job to the best of their ability and exactly as told. The chemical companies which monitor the system will prove themselves blameless because their dosage was always within guidelines. How do we optimize the process? At this point, one needs to rely on historical data.

In making any assessment from plant data it is important that the difference between perfect samples and real samples is taken into account. In the sampling process itself, the sample undergoes many changes. All specifications must reflect these changes. In a typical boiler plant these could include:

1. The sample will be cooled. Most laboratory measurements are made at 25°C. After cooling, pH rises; conductivity drops. Some materials become less soluble and precipitate, while others become more soluble. Hydrolysis of deposits may increase or decrease.

2. Flow rates and directions will change. If the flow decreases, particulates may drop out of suspension. The sampling system itself may add particulates as the valve is opened.

3. As the sample is depressurized, it loses dissolved gases then starts to pick up contamination from the atmosphere.

4. The system has a large volume. The sample volume is small. At these low concentrations, the various components are not necessarily distributed uniformly throughout the system.

Looking at the previous page, it must be recognized there is no such thing as an absolute to the analytical work. It is an altered sample of possibly uneven distribution. The goal must be to find changes and relate these to performance.

4.2 DATA AND REPORTING

The required format for the data will be very dependent upon the time scale required for the analysis:

Short-term upsets in plant operation will tend to be detected by individual analyses. The plant operator will react to each individual data point as it arrives. On the time scale of hours to weeks, it will be common to graph the data to watch for changes that might occur.

Over the long run, these upsets and changes will tend to average out and the need will be for long-term statistical summaries. We have to be able to answer such questions as:

1. Is data really in spec or crowding either the top or bottom of the limits. If so what does it mean? Have numbers been reliable or has data been lost within a background? ....or due to sampling techniques?

2. Is it actually possible ....or reasonable to strive for operation within the limits? .....or should the operational limits be altered to reflect the realities of the system?

3. Have the manufacturer's specifications been met with respect to any warranty or performance guarantees?

4. If new evidence (*eg.* from new metallurgical information) indicates a change of spec, how long would it take to assess compliance or deviation from this new value?

5. Are there distinctive differences between "identical" units or under "identical" conditions?

Short-term data collection and analysis procedures will be very dependent upon the nature of the plant operation and its personnel. There is no single method that should be used. Generally the methods chosen work for the people involved.

Operators rarely do anything with long-term data. The fires have been fought and the plant is operating. A complacency creeps into the operation. Why look for problems that don't exist? Without constant surveillance, there will be problems and they will come when least expected. A surprise can shut down a plant and stop production. It may also cause severe damage and an extended unplanned outage. On the other hand, an anticipated repair can be planned for a scheduled maintenance outage with an orderly shutdown that is less likely to severely curtail production or damage equipment.

Long-term data comes from short-term data, but the two are not interchangeable. Short-term data monitors the plant, as it operates, and must point out any need for immediate response. The data must then be further processed for long-term use. It is this step that is often overlooked. In the heat of "fire fighting" errors are often made in trying to quickly extract information. The result is usually an attempt to solve symptoms rather than problems. A short-term solution to a long-term problem will, in all likelihood, lead to another crisis down the line

a. **Tabulation**: In plant logs, data is put down on paper. Some plants have daily logs which list only numbers for the day. ..are they in or out of spec? Some plants use an on-going tabulation of the numbers from day to day. While a table may include all of the numbers produced, it is extremely difficult to see trends or variations. In most cases tables are filed and never used.

b. **Mean & standard deviation**: These values are easily calculated even with a relatively inexpensive hand calculator. A large quantity of data can be reduced to a fairly small table of numerical data that can be used as the basis for comparisons. The method is best suited to batch type analyses, *eg.* monthly summaries. It is a rough averaging technique. The mean and the size of the standard deviation can be plotted in the form of a **control chart** to give some indication of the degree of control.

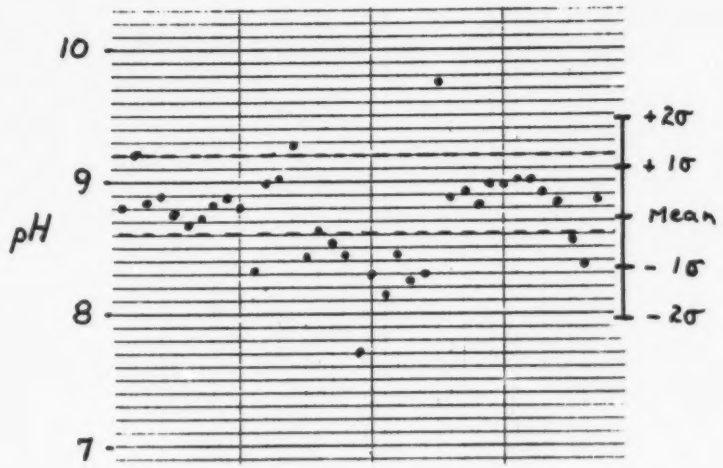
c. **Graphic trends**: Graphs provide the best indication of transients, but have a tendency to get involved or messy particularly if they are done manually by several people over a long period of time. Graphs provide extremely useful data over the short to mid-term; over the long term they tend to require some form of averaging, which loses some of the transient data. The degree of spreading of the data points may be hard to determine and so graphs should be done in conjunction with histograms or other statistical techniques. Graph preparation can be readily adapted to either manual or computer techniques.

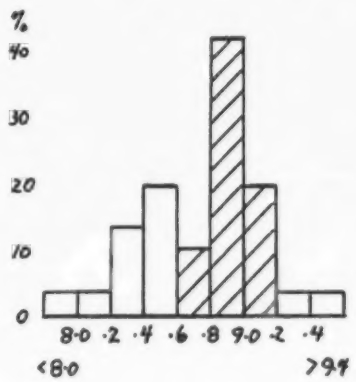
d. **Histograms**: Histograms provide a rapid assessment of long-term performance. They read directly in percentage of time within or outside limits. They are a long-term indicator and average all transients into a single operating record. They are easily and quickly read. This is an advantage when looking at many systems, each with several variables, as the entire history can be reduced into patterns the eye can readily scan and comparisons. Histograms are readily prepared by either manual or computer techniques.

Pages 69 and 70 compare the display of data using the various approaches. Combining the above ideas, the reporting sheet shown on page 71 was designed to allow a rapid on-going assessment of data. The data is entered as a block to show a graphical trend. At the same time, a block is entered in the squares on the right to produce a histogram. This reporting sheet is usable by operators in the field and gives them a rapid indication of system status and helps in early detection of upsets.

4.3 TIME SERIES ANALYSIS

Going one step further, with modern computer techniques, it is a relatively simple matter to integrate a number of simple statistical techniques into a simple program that can transform data into a form which not only produces a well managed record, but also uncovers hidden movements not readily visible to the eye. The technique used is **time series analysis** where a Time Series is defined as a set of observations taken at specific times, usually, but not necessarily, at equal





COMPARISON OF DATA PRESENTATIONS
for
INFORMATION CONTENT

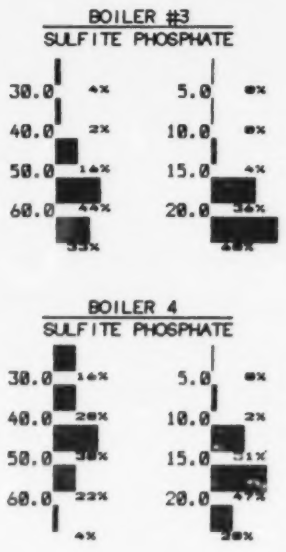
The same data has been presented as a graph, with the mean and standard deviation indicated, and as a histogram. This data is the pH of boiler feedwater with the recommended operating range indicated by the broken lines on the graph and cross hatching on the histogram.

METRO TORONTO BOILER SYSTEM - ANALYSES FOR TWO-WEEK PERIOD

DATA IN TABLE FORMAT

DATE	BOILER #3 SULFITE	BOILER #3 PHOSPHATE	BOILER #4 SULFITE	BOILER #4 PHOSPHATE
NOV-01	60	22	36	14
	60	22	32	15
	56	22	34	16
NOV-02	66	24	40	15
	60	24	42	16
	54	24	32	14
NOV-03	60	24	40	17
	62	24	40	18
	60	23	42	19
NOV-04	70	24	40	20
	58	24	38	22
	56	23	28	19
NOV-05	60	22	32	18
	60	24	46	20
	64	24	44	23
NOV-06	70	24	48	24
	70	24	62	24
	64	24	56	24
NOV-07	60	21	60	24
	64	22	66	24
	60	24	60	24
NOV-08	66	24	48	18
	60	24	30	24
	70	24	32	17
NOV-09	82	24	50	20
	84	24	56	18
	70	22	58	18
NOV-10	50	19	56	20
	52	16	54	18
	42	17	44	17
NOV-11	48	16	60	18
	56	20	50	16
	52	20	60	12
NOV-12	52	20	56	14
	60	20	50	15
	76	20	50	16
NOV-13	70	18	46	12
	58	18	32	15
	48	18	32	14
NOV-14	40	19	20	14
	40	18	20	15
	40	16	40	16
NOV-15	20	15	18	13
	26	14	18	8
	34	18	18	10

DATA IN HISTOGRAM FORMAT



The table does not show that the dosage is on the heavy side. It shows very clearly when the data is presented in the histogram format. The dosage could actually be cut in half or more if this better control was in effect.

The recommended dosages are:

30 - 50 mg/kg sulfite
5 - 15 mg/kg phosphate

Daily Log Sheet

Building: PHYSICAL PLANT | Location: METROPOLITAN TORONTO | Report Number: | Month/Year: NOV 81

Plant Personnel: | System: BOILER # 4

DAY 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

UNITS mg/kg

60 50 40 30 20 10

INITIAL

36 32 34 40 42 32 40 40 42 40 38 28 32 46 44 48 62 56 60 66 60 48 30 32 50 56 58 56 54 44 60

FREQUENCY DISTRIBUTION

0 5 10 15 20 25

TEST: SULFITE

recommended 30-50 mg/kg

DAY 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

UNITS mg/kg

30 25 20 15 10 5

INITIAL

14 16 16 15 16 14 17 18 19 20 22 19 18 20 23 24 24 24 24 24 24 18 24 17 20 18 18 20 18 17 18

FREQUENCY DISTRIBUTION

0 5 10 15 20 25

TEST: PHOSPHATE

recommended 5-15 mg/kg

DAY 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

UNITS

INITIAL

FREQUENCY DISTRIBUTION

0 5 10 15 20 25

TEST:

*PLACE IN APPROPRIATE BLOCKS AND SUPER IMPOSE UPPER AND LOWER LIMITS

COMMENTS: DOSAGE TOO HIGH

WILL REQUIRE EXCESSIVE BLOWDOWN

Service Representative: _____ DATE _____ SIGNATURE

Reviewed by: _____ DATE _____ SIGNATURE

intervals. The characteristics which describe a time series can be ascribed to: random movements, trends and cyclic movements.

a. **Random Movements**: Two simple tests for randomness are discussed here: positive first differences; and turning point analysis. No single test for randomness is conclusive by itself. The positive first difference is insensitive to period variations, but sensitive to trends; the turning point test is not sensitive to mild trends, but will react to strong trends. Both are considered as either one may react differently from the other in any given set of data.

The basis of the **positive first difference test** is that, for random data, half the first differences or differences between consecutive values, would be positive and half negative, *ie*.

$$\textit{expected number of first differences} = 1/2 \times (n-1)$$

The basis of the **turning points test** is that a turning point is considered to exist if a data point is higher or lower than its neighbours. The expected number of turning points for a random sequence is given by:

$$\textit{number of turning points} = 2/3 \times (n-2)$$

If either the calculated positive first differences or turning points from the data differ widely from the expected values, this indicates that the data is not random, but may have a trend or period .... or some other type of order and this data should be subjected to some additional analysis.

b. **Trends**: **Kendall's Tau test** compares each data point with every later point. Each time the later point is greater, 1.0 is added to the tally, for equal points, 0.5 is added. If Tau exceeds 1, an increasing/decreasing trend is indicated. If Tau equals 0, there is no trend. Intermediate values indicate that there may be a trend, but it can't really be confirmed with a sufficiently high level of confidence.

c. **Periodicity:** Many sophisticated programs exist to determine the presence of periodic components (MIeg. seasonal variations) in data. Unfortunately, harmonic analysis may detect periodicity which does not exist. For most data sets collected in water systems, programs incorporating Fourier Analysis are inappropriate. A simple prescreening test seems more suited to the type of data and its end use. The one used is **Alter's Test** which defines a series of absolute differences between the terms in a data series and the terms preceding them. In use, Alter's test develops a number of time lags with an average difference for each. If there is a periodic component, they show an undulating pattern. If there is no periodic component they will be constant or perhaps increasing or decreasing if there is a trend.

The techniques mentioned above are simple. They are also adaptable to relatively simple computer techniques. The best interpretation of the data is usually based upon a combination of these techniques and a measure of common sense.....and an understanding of the process being studied. Some examples of the application of these techniques are shown in the **electronic log sheet** shown on the following page. This type of log has the advantage over the standard type of log in that it does all these statistical tests and summarizes the results **objectively**, but leaves the actions to the operator. It was written in BASIC and could be prepared by anyone familiar with programming.

The data is compiled from real data to demonstrate the reaction to the various trends. The data sets are:

1. periodic data with a one year cycle

2. the same data increased to a half year cycle

3. slowly rising data superimposed upon a constant background level

4. the same reversed

5. boiler data showing randomness

T-I-M-E-S TIME-SERIES ANALYSIS

TEST DATA FOR TIME SERIES ANALYSIS

DATE	SLOW CYCLE	FASTER CYCLE	RISING	FALLING	RANDOM	BIASED
JAN-88	4.0	6.3	277.0	522.0	36.0	36.0
FEB	4.0	12.0	303.0	515.0	40.0	40.0
MAR	5.6	20.0	310.0	499.0	40.0	40.0
APR	8.2	13.4	330.0	481.0	40.0	40.0
MAY	15.0	4.5	337.0	473.0	32.0	40.0
JUN	15.5	3.4	356.0	461.0	48.0	48.0
JUL	20.3	5.6	359.0	459.0	32.0	35.0
AUG	19.3	15.0	386.0	452.0	42.0	35.0
SEP	12.8	20.3	405.0	426.0	40.0	35.0
OCT	7.8	12.8	426.0	405.0	38.0	35.0
NOV	3.4	3.4	452.0	386.0	46.0	35.0
DEC	3.8	3.4	459.0	359.0	62.0	30.0
JAN-89	3.4	6.2	461.0	356.0	34.0	35.0
FEB	3.4	13.1	473.0	337.0	32.0	35.0
MAR	6.2	18.6	481.0	330.0	42.0	35.0
APR	8.8	13.3	499.0	310.0	38.0	35.0
MAY	13.1	4.8	515.0	303.0	48.0	44.0
JUN	18.2	3.8	522.0	277.0	44.0	44.0
TOTAL = 18						
MEAN	9.6	10.8	408.4	408.4	40.8	37.6
STD DEV	6.8	6.1	78.4	78.4	7.3	4.4
-AS %	62.6	61.3	19.2	19.2	18.0	11.8
MINIMUM	3.4	3.8	277.8	277.8	32.8	30.8
MAXIMUM	20.3	20.3	522.8	522.8	62.8	48.8

DISTRIBUTION OF ANALYTICAL DATA	SLOW CYCLE	FASTER CYCLE	RISING	FALLING	RANDOM	BIASED
	5.0 33%	5.0 33%	300.0 6%	300.0 6%	35.0 22%	35.0 94%
	10.0 28%	10.0 17%	350.0 22%	350.0 22%	40.0 17%	40.0 6%
	15.0 17%	15.0 33%	400.0 17%	400.0 17%	45.0 39%	45.0 33%
	20.0 6%	20.0 11%	450.0 11%	450.0 11%	50.0 17%	50.0 6%
						0%

RANDOMNESS: MORE THAN ONE BLOCK IN A AND/OR B INDICATES ORDER

A. POSITIVE FIRST DIFFERENCES - NUMBER EXPECTED IF RANDOM = 8.5

SD ± 1.2	10	---->\<----	8	---->\<----	17	---->\<----	8	---->\<----	7	---->\<----	4	---->\<----

B. TURNING POINTS - NUMBER EXPECTED IF RANDOM = 10.7

SD ± 1.6	4	---->\<----	5	---->\<----	8	---->\<----	8	---->\<----	11	---->\<----	2	---->\<----

TRENDS: KENDALL'S TAU - MORE THAN ONE BLOCK INDICATES A RISE OR FALL

SD ± 0.2	+0.0	---->\<----	-0.1	---->\<----	+1.0	---->\<----	-1.0	---->\<----	+0.2	---->\<----	-0.2	---->\<----

PERIODS: ALTER'S TEST - PLOT OF AVERAGE DIFFERENCES

1	2.9	---o----	3.6	---o----	14.4	o----------	14.4	o----------	0.2	----------o-	2.6	---o----
2	3.6	---o----	7.1	----------o-	28.6	---o-------	28.6	---o-------	0.3	----------o-	3.6	----o----
3	7.7	----------o-	11.8	----------o	43.1	----o------	43.1	----o------	0.2	----------o-	5.2	----o----
4	9.8	----------o-	8.3	----------o-	56.9	-----o-----	56.9	-----o-----	10.8	----------o	4.9	----------o-
5	10.6	----------o	5.2	----o------	71.8	------o----	71.8	------o----	0.6	----------o-	5.6	----------o
6	10.6	----------o	1.8	o----------	86.3	-------o---	86.3	-------o---	0.8	----------o-	5.2	----------o-
7	9.9	----------o-	5.9	----o------	103.5	---------o-	103.5	---------o-	0.3	----------o-	5.2	----------o-
8	7.8	----------o-	9.3	----------o-	120.4	----------o-	120.4	----------o-	0.8	----------o-	5.7	----------o-
9	6.1	----------o-	10.9	----------o	136.1	----------o	136.1	----------o	0.4	----------o-	6.3	----------o

07-16-1987 T-I-M-E-S (C) 1987 by MARVIN SILBERT AND ASSOCIATES

6. the same with numbers entered to indicate values expected, but not necessarily obtained

The hard numbers are retained and made visible with the bar charts. The bars have been scaled to emphasize the maximum differences between the highest and lowest values using ten blocks. The bars clearly show the periodic variations and up/down trends.

a. The first differences indicate randomness on the cyclic and random boiler data while the turning points indicate randomness only on the random boiler data. This would be expected as cycles and trends are ordered data. The data prepared from biased data "without doing the analyses" lacks the statistical variations that are expected in real data.

b. Kendall's Tau test confirms the expected up/down trends.

c. Alters's test shows periods in the cyclic data. It tries to find a period in the rising/falling data.

It must be pointed out that the data chosen for the demonstration has very visible order and it would be expected the tests would be able to confirm the obvious. In day-to-day operation this technique has been used on data with less obvious order and made it stand out where it was essentially invisible to the eye.

This program differs from database and spreadsheet programs in that it does much more than filing. Great care must be made when computerizing data to ensure that the process is more than just a change from a manual filing system to a computerized filing system.

5

APPLICATION TO HOSPITAL SYSTEMS AND RECOMMENDATIONS FOR FUTURE INSTALLATIONS

A number of hospitals were visited to investigate whether or not the recommended methods for energy savings were realistic and possible. They included plants that use Great Lakes water as well as those using well water.

5.1 COOLING WATER SYSTEMS

All of the hospitals visited were operating their towers in the region of 3.0-3.5 cycles of concentration regardless of water supply. One of these was using softened well water. There is a water savings potential of as much as 20-25 percent to be gained by going from these values up to perhaps 6-7 cycles of concentration. This level should be possible with some combination of improved products and softened or partially softened water.

All plants reported that the condensers were clean when opened for inspection. "Clean" is a rather subjective term and is dependent upon the interpretation of the reporter. These systems are operating on that fine line between success and failure with no adequate means of guaranteeing that they will stay in the realm of success. If a sudden increase in fouling occurred, air conditioning efficiency could drop dramatically. The immediate need is for a tighter means of controlling the operation. This could include efforts both in the methods by which water treatment is monitored and controlled and the equipment installed.

Improved monitoring programs

a. A means of quantifying the word "clean" with respect to the cleanliness of the air-conditioner condenser. The water-treatment chemical-control log was not integrated with the air conditioner log. Coupling the operation of the

two together is required to find any relation indicating whether or not there is an efficiency loss related to the cooling tower operation eg. a loss of efficiency for the chiller may be indicating a fouling of the condenser surfaces.

b. Regular microbiological testing using "dip-type" testers and adjustment of biocide feed is needed. The frequency should be 2-3 times per week in the summer peak and less during the cooler periods. The estimated cost will be about $4.00 per test. None of the hospitals were conducting regular microbiological testing. The use of this test is part of a preventive maintenance program to prevent fouling.

Improved Equipment

a. Installation of filtration to remove particulates and debris. One plant reported a significant improvement in cleanliness after addition of screens that removed debris from grass cutting operations that blew into the tower. Costs for this type of system will be dependent upon the choice of filter and the number and size of lines carrying cooled water from the cooling tower(s). For a 1,000 ton air conditioning unit the cost will be between $5,-15,000.

b. Installation of the bleedoff on the warm return line rather than from the cooling tower sump. It was already installed this way at a number of the plants. For those that aren't, relocation of the solenoid valve could recover the equivalent cost of air conditioning up to 5-10,000 square feet. The location should be specified as part of the general specifications for any new plants to be constructed.

c. Installation of or connection to a softened water supply for makeup to the cooling tower. The cost for this change could be minimal where softening equipment is already available and the length of lines required is small. Alternatively, several of the water-treatment vendors can supply programs that allow operation at higher cycles of concentration.

The use of free cooling did not appear to be a viable option for any of these plants as they did make use of outside air during the cooler periods.

Discussion

In the plants visited, there was no indication of any water-related problems with the cooling systems. However, there is no quantitative means of actually measuring the performance of these systems and guaranteeing that they will continue to open up "clean". The lack of problems can thus be explained more on the basis that the problems, if any, are hidden away. Such an approach leaves the system ready for unpleasant surprises.

In a typical large hospital, air conditioning capacities will be in the order of 1,000 ton or larger. A film only 0.012" thick can require an additional $7,000 in electrical energy costs. Such a deposit, to the eye, may appear "clean". The measurements to see whether or not the system is really "clean" are at present not performed. The chances for a sudden event that can start the build up of a deposit have a probability that is high. It takes only a failure to add biocide during a high pollen cycle or a period of local construction. This material gets into the tower and the buildup of the deposit begins.

The actions required to guarantee cleanliness are simple and straightforward. Monitor for microbiological fouling and provide continuous filtration. The monitoring is cheap. Adequate filtration is not cheap, but it is an insurance policy against possible fouling. The cost of tube cleaning is not cheap. Even with the use of in-house labour, a cleaning may cost $2-3,000. If acid cleaning is required, there is a severe potential for damage to the system.

5.2 BOILER WATER SYSTEMS

Several of the plants used conventional water treatment for their boiler feedwater. The main methods for improvement fit into the two categories of improved records and reduced blowdown through improved water quality.

Improved Record Keeping

A major weakness in boiler programs is that they have not been established to follow plant operation as much as chemical consumption. The same sampling and analysis program can be modified slightly to maintain an on-going record of

losses in the system. Regular sampling should include measurement of chlorides in the makeup, feedwater, blowdown and condensate. From these, the percentage losses and blowdown can be calculated. Once these are recorded, the ability for in-house action to reduce these can be facilitated.

One of the plants appeared to be a very tight system with less than 1 percent makeup while the others averaged makeup in the 10-20 percent range.

Boilers are inspected on an annual basis as part of the insurance requirements. This inspection involves a physical entry into both the steam and mud drums. There is little knowledge of the condition of the tubes themselves as it is not possible to see past the bends. Remote sensing equipment can be made available in the form of Haskin's Turner gauges, for measuring deposit thicknesses, and fibre optics, for seeing around the bends. Most reputable water-treatment vendors can supply the equipment for an inspection. Alternatively, this type of equipment could be rented or jointly purchased.

Reduced Blowdown Through Improved Water Quality

Two of these plants had 3-4 percent continuous blowdown. Assuming a 50 percent recovery of the heat lost, this accounted for an energy loss of about $5,000 per year. The cost of a reverse osmosis system was estimated for each of these applications. This choice of system was made because it does not add a waste handling problem to an already busy physical plant and also because there is an increasing level of experience with reverse osmosis equipment for other hospital systems.

Example 1: Present system - polishing sodium softener and chloride dealkalizer fed from softened well water: In this system, the existing system can be removed and replaced with a reverse osmosis system. The cost of resin regenerations will approximately balance the operating and maintenance cost of the reverse osmosis equipment. The needed capacity was 3 gpm which could be supplied for approximately $15,000. To maximize throughput, the feed should be about 25°C.

Installation of this equipment would reduce the blowdown to well below 1 percent recovering about $5,000 per year. With the reduced blowdown, chemical costs would be reduced. They are small now and this would only account for about $500 per year additional savings.

The big factor, which can't be documented, is the potential savings on fuel. While boiler inspections show a clean system, they can't really determine the thickness of the deposition on the tubes as these can only be seen if and when there is a failure and a tube removed. A steady-state thickness of 1.0 mm of calcium phosphate can reduce the boiler's efficiency by about 9 percent; it may have little or no effect if the heat is absorbed elsewhere in the boiler. It is also possible that the deposit may end up as a hot spot that fails and causes expensive maintenance. The chances for such a deposit fall rapidly as the water quality improves. This type of savings may show up as energy costs are evaluated after a changeover.

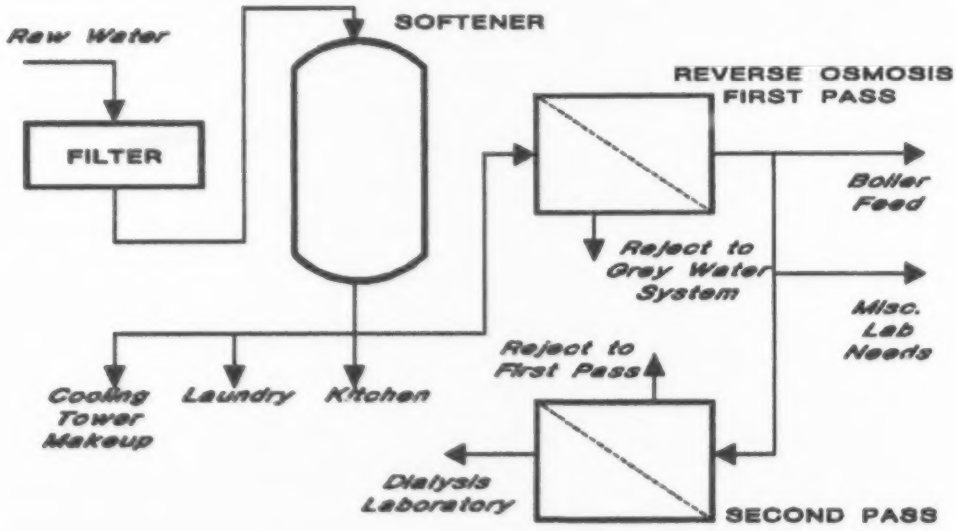
Example 2: Present system - softened city water: This system uses a softener to remove hardness from the city water. Typical blowdown levels are about 3 percent which at 50 percent recovery corresponds to about $3,000 per year. A reverse osmosis unit supplying 1.5 gpm would meet the needs here and would cost about $8,000. The sodium softener should remain as the front-end treatment to protect the reverse osmosis equipment, so its operating cost will also remain low. The annual cost of operating the reverse osmosis equipment would be about $1,000.

Discussion

In the above examples, the payback for installing reverse osmosis equipment appears small and perhaps inadequate based upon blowdown alone. There will be additional savings with respect to the treatment chemicals. With the present blowdown of 3 percent, the chemical feed must replenish the products almost daily to keep the levels up. With a lower blowdown, the products will concentrate more and remain present longer. This will result in a saving of approximately $1-2,000 per year and a cleaner boiler

The use of reverse osmosis for boiler feed has not yet been generally accepted in the industry as a standard procedure applied to boiler-plant operations although the technology is quite straightforward and those applications where it is used perform exceptionally well. In looking for representative locations utilizing this technique it was found within one hospital in Ontario. York Central Hospital in Richmond Hill now has almost ten years operation with this type of system. This plant originally operated from well water, but now uses Lake Ontario water. The original softeners remain in service and supply the feed to the reverse osmosis equipment. They find a much reduced use of water-treatment products and almost zero blowdown giving an extremely clean boiler.

The factor that helps to fully justify reverse osmosis feed for the boilers is that high quality water is used for more than the one application within a hospital. It also meets the needs for other applications such as laboratory needs, kidney dialysis, etc. Reverse osmosis systems have been installed for the other applications and the option that should be looked into here is an integrated pure water supply.



INTEGRATED WATER SYSTEM FOR HOSPITAL

In applications where reverse osmosis equipment is already installed to meet other hospital needs, it may be possible to reduce the equipment cost for including boiler feed. As the existing system already contains pumps and controls; it may only be necessary to add some extra membranes to cover the added capacity. In new installations, the need is for a look at the entire water usage for the hospital and to treat the boiler needs together with the various laboratory functions. The laboratory needs more water than the boilers and of a higher quality. This is accomplished with a double-pass reverse osmosis unit. By sizing the first stage somewhat larger, it can supply the needs for the boiler at very low additional (perhaps only a few thousand dollars extra) cost. At the same time, this cost is more than recovered by the elimination of a separate system for boiler feed.

5.3 INDIVIDUAL *vs* COMBINED APPROACH

At the present time, hospitals meet their water-treatment needs on the basis of using outside suppliers for both the products required and the services of a technical representative. They act individually with no effort to utilize their large base within the province. As such, there are large variations in both the programs and the quality of service from location to location. This also reflects in pricing.

By pooling resources, standardized programs and suppliers could be utilized with pricing minimized through the tendering process. A cost savings exceeding 25 percent could be achieved with respect to products and services which now are typically in the $10,000 range annually for a major hospital. At the same time, this large base would ensure an adequate level of technical service to the smaller hospitals that purchase very little in the way of products.

Much of the so-called free service that comes with water-treatment products is aimed at the small plant that does not have full-time personnel involved in water treatment. Hospitals tend to have a well-trained staff on duty around the clock. The service that these people supply is far superior to that of the technical representative, but at this time is not reflected in the price structure.

5.4 RECOMMENDATIONS FOR FUTURE WORK

A number of actions are required to develop a significant savings within the province. These include:

a. The first stage in saving energy is to provide each hospital with the information needed to measure, on a daily basis, the losses and blowdown from the system and to set targets for their control. This is probably best done by developing a standardized work sheet for reporting boiler analyses and mass balance calculations enabling each plant to do these on an on-going basis. The calculations to carry out a boiler mass balance are discussed in detail in section 3.

   A representative number of plants should be followed in detail to see if the availability of the knowledge is followed up with corrective actions to reduce losses. As part of the process, a training program should be instituted for physical plant personnel to ensure that they are able to carry out this type of monitoring.

b. Conduct a survey of all physical plants within the province to summarize such data as:

   - the types of equipment

   - pretreatment and chemical products used

   - performance of HVAC water systems

   - maintenance requirements related to water

   - other water requirements, *eg.* laboratory systems

   From this, establish a data base on which to evaluate the various types of systems and a standardized reporting and treatment system. This data base could also be used for developing required standards for the type of equip-

ment to be specified within new or expanded facilities. This data base could also be used to develop a region or province-wide approach to the purchase of chemical treatment products to enable the hospital system to obtain a big-customer pricing structure rather than the present structure based on being treated as individual small customers.

c. Select one or two representative plants for upgrading to a reverse osmosis boiler feed system. These plants should be monitored with respect to their blowdown rates and overall energy costs as well as chemical treatment costs before and after the changeover. One of these choices should be a plant where reverse osmosis is already used for other applications and possibly another now in the planning stage.

CAUTIONARY NOTICE

This report attempts to utilize available data plus related experience to put together a realistic overview of the operation and possible methods for conserving energy within hospital HVAC and boiler water systems. As conditions specific to individual plants may lead to interpretations that differ from those presented, no liability can be assumed for any direct or indirect damages, however caused from reliance upon or application of the contents of this report by any person to any specific plant or system.

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